US009365237B2

(12) **United States Patent**
Takeda

(10) **Patent No.: US 9,365,237 B2**
(45) **Date of Patent: Jun. 14, 2016**

(54) **STEERING CONTROL DEVICE**

(71) Applicant: **Nissan Motor Co., Ltd.**, Yokohama-shi, Kanagawa (JP)

(72) Inventor: **Yuya Takeda**, Yokohama (JP)

(73) Assignee: **Nissan Motor Co., Ltd.**, Yokohama (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/759,265**

(22) PCT Filed: **Dec. 5, 2013**

(86) PCT No.: **PCT/JP2013/082718**

§ 371 (c)(1),
(2) Date: **Jul. 6, 2015**

(87) PCT Pub. No.: **WO2014/109151**

PCT Pub. Date: **Jul. 17, 2014**

(65) **Prior Publication Data**

US 2015/0353127 A1 Dec. 10, 2015

(30) **Foreign Application Priority Data**

Jan. 10, 2013 (JP) 2013-002376

(51) **Int. Cl.**
B62D 6/00 (2006.01)
B62D 5/04 (2006.01)

(52) **U.S. Cl.**
CPC ***B62D 5/0469*** (2013.01); ***B62D 5/0466*** (2013.01); ***B62D 6/008*** (2013.01)

(58) **Field of Classification Search**
CPC B62D 5/0469; B62D 5/0466; B62D 6/008
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,236,884	B2 *	6/2007	Matsumoto	B60T 8/17557 340/435
7,530,423	B2 *	5/2009	Limpibunterng	B62D 5/008 180/444
2002/0038171	A1 *	3/2002	Deguchi	B62D 7/159 701/41
2007/0029129	A1 *	2/2007	Shiozawa	B62D 6/04 180/446

FOREIGN PATENT DOCUMENTS

JP	2004-196069	A	7/2004
JP	2008-1117	A	1/2008
JP	2008-120288	A	5/2008
JP	2010-30503	A	2/2010
JP	2010-100119	A	5/2010
JP	2011-84165	A	4/2011

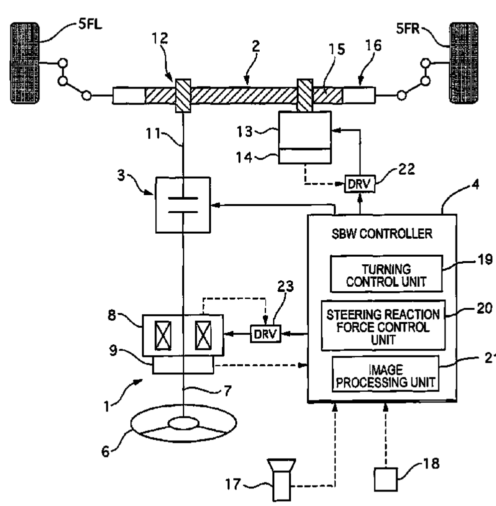
* cited by examiner

Primary Examiner — Calvin Cheung
(74) *Attorney, Agent, or Firm* — Global IP Counselors, LLP

(57) **ABSTRACT**

A steering control device set a steering reaction force characteristic to coordinates so that the self-aligning torque increases as the steering reaction force increases. Upon applying a steering reaction force corresponding to the self-aligning torque to a steering unit based on the steering reaction force characteristic to offset the steering reaction force characteristic at coordinates more in a direction in which an absolute value of the steering reaction force increases as a lateral position of a host vehicle approaches to a white line, the offset of the steering reaction force characteristic is suppressed when a turn signal operation is started while suppression of the offset of the steering reaction force characteristic is released when the turn signal operation is ended so that an absolute value of an increase gradient when releasing suppression of the offset becomes smaller than an absolute value of a decrease gradient when suppressing the offset.

8 Claims, 16 Drawing Sheets



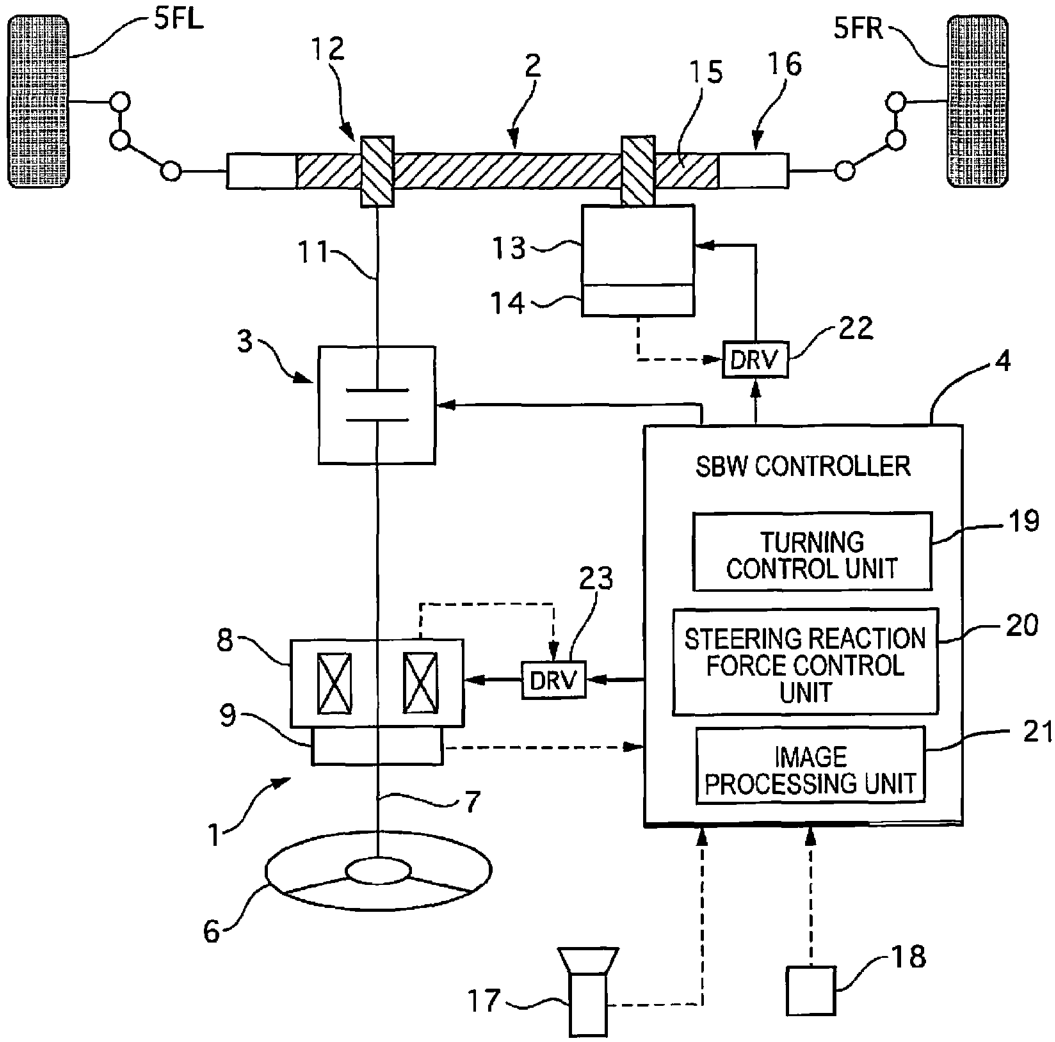

5FL
12
2
15
16
5FR
11
13
14
22
DRV
3
4
SBW CONTROLLER
TURNING CONTROL UNIT
19
STEERING REACTION FORCE CONTROL UNIT
20
IMAGE PROCESSING UNIT
21
23
8
DRV
9
1
7
6
17
18

FIG. 1

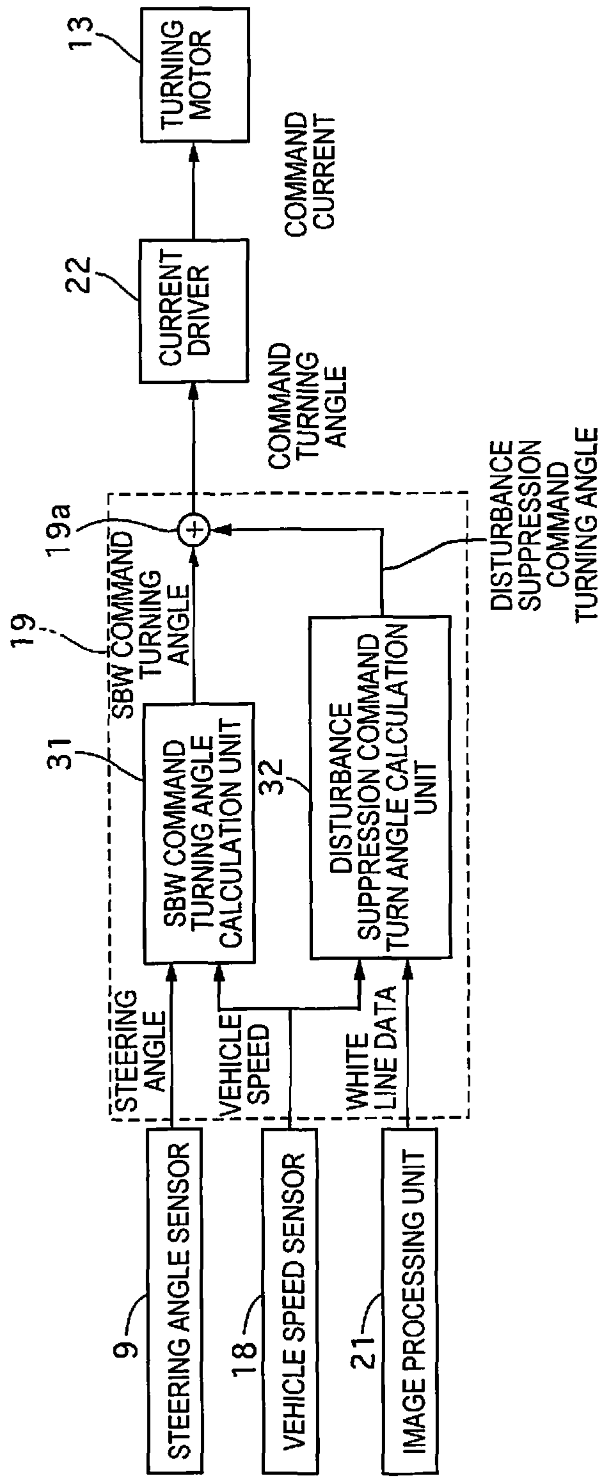
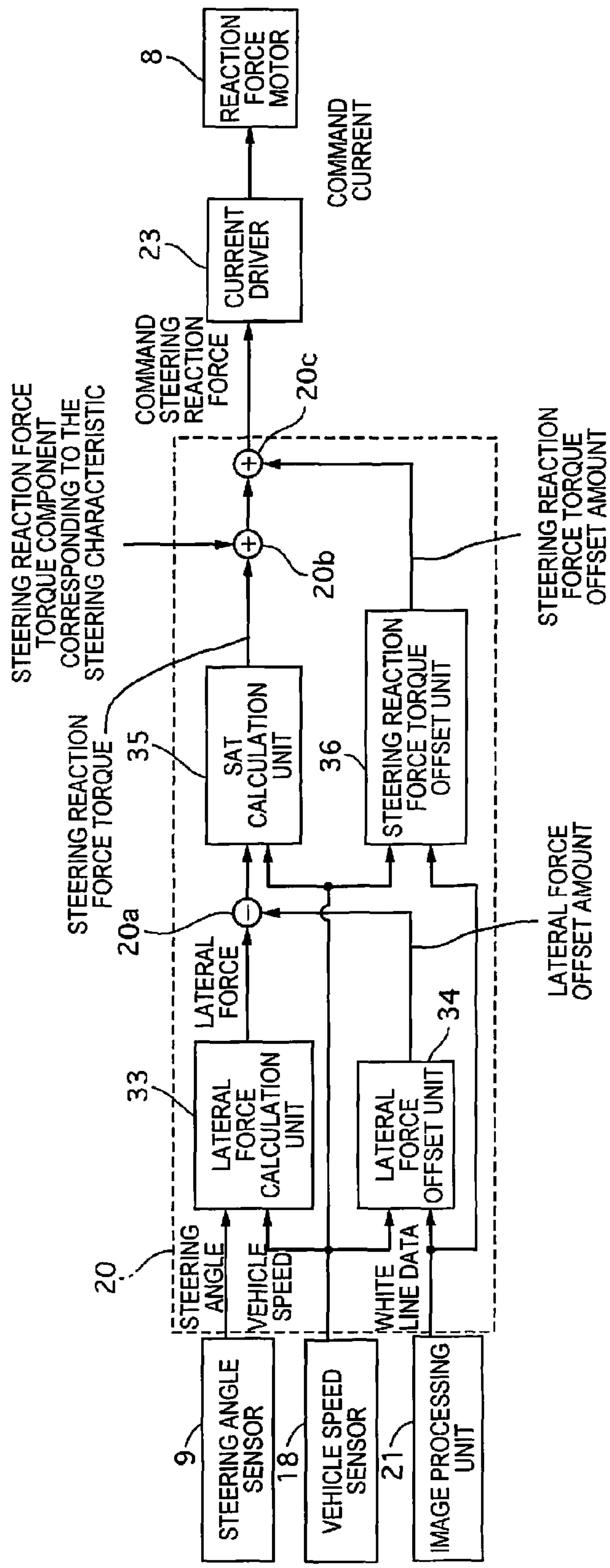

13
TURNING MOTOR
COMMAND CURRENT
22
CURRENT DRIVER
COMMAND TURNING ANGLE
19a
19
SBW COMMAND TURNING ANGLE
DISTURBANCE SUPPRESSION COMMAND TURNING ANGLE
31
SBW COMMAND TURNING ANGLE CALCULATION UNIT
32
DISTURBANCE SUPPRESSION COMMAND TURN ANGLE CALCULATION UNIT
STEERING ANGLE
VEHICLE SPEED
WHITE LINE DATA
9
STEERING ANGLE SENSOR
18
VEHICLE SPEED SENSOR
21
IMAGE PROCESSING UNIT

FIG. 2



STEERING ANGLE SENSOR
9
VEHICLE SPEED SENSOR
18
IMAGE PROCESSING UNIT
21
20
STEERING ANGLE
VEHICLE SPEED
WHITE LINE DATA
LATERAL FORCE CALCULATION UNIT
33
LATERAL FORCE OFFSET UNIT
34
LATERAL FORCE
LATERAL FORCE OFFSET AMOUNT
20a
STEERING REACTION FORCE TORQUE
SAT CALCULATION UNIT
35
STEERING REACTION FORCE TORQUE OFFSET UNIT
36
STEERING REACTION FORCE TORQUE COMPONENT CORRESPONDING TO THE STEERING CHARACTERISTIC
20b
STEERING REACTION FORCE TORQUE OFFSET AMOUNT
20c
COMMAND STEERING REACTION FORCE
CURRENT DRIVER
23
COMMAND CURRENT
REACTION FORCE MOTOR
8

FIG. 3

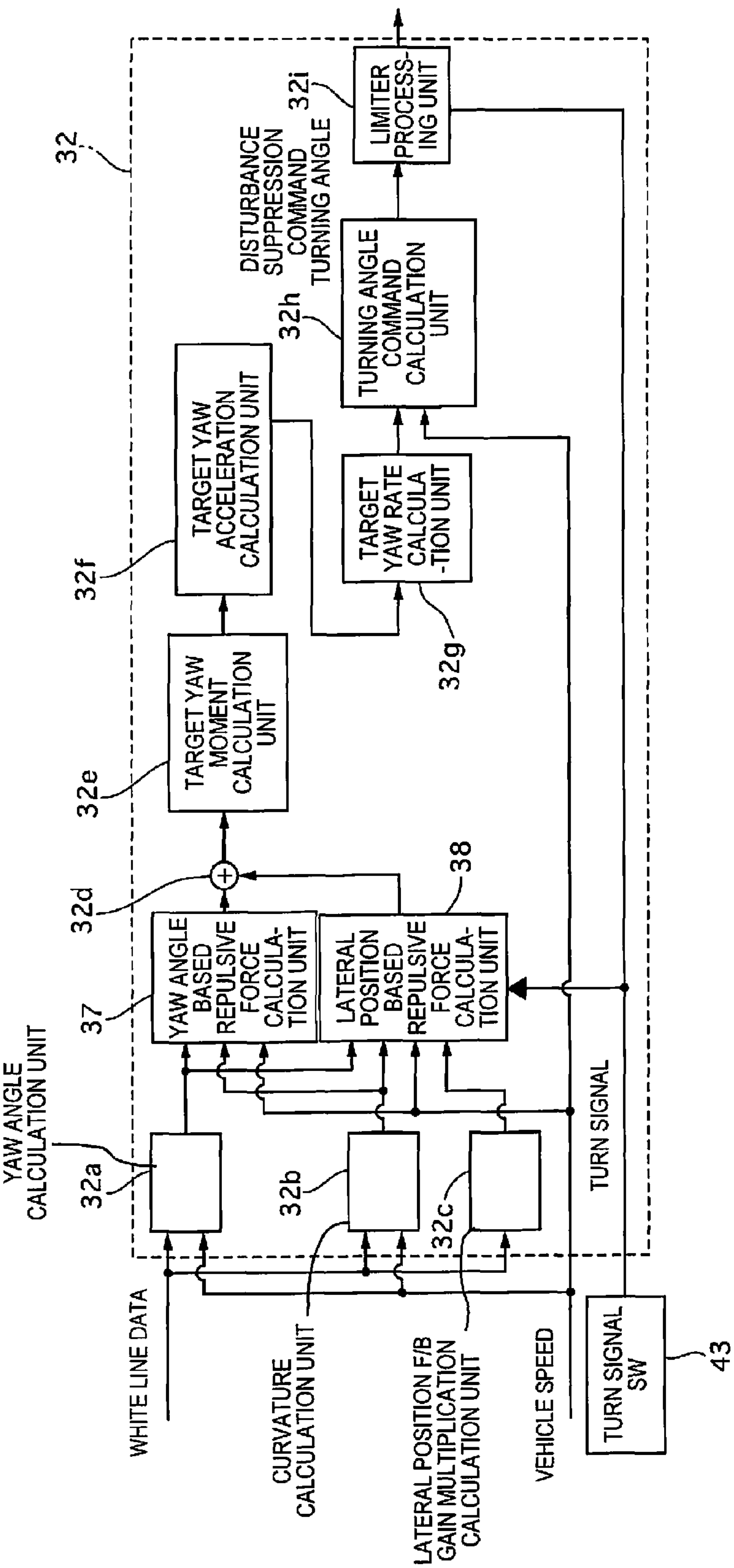

32
32i
LIMITER PROCESSING UNIT
DISTURBANCE SUPPRESSION COMMAND TURNING ANGLE
32h
TURNING ANGLE COMMAND CALCULATION UNIT
TARGET YAW ACCELERATION CALCULATION UNIT
32f
TARGET YAW RATE CALCULA-TION UNIT
32g
TARGET YAW MOMENT CALCULATION UNIT
32e
32d
38
YAW ANGLE BASED REPULSIVE FORCE CALCULA-TION UNIT
LATERAL POSITION BASED REPULSIVE FORCE CALCULA-TION UNIT
37
YAW ANGLE CALCULATION UNIT
32a
32b
32c
TURN SIGNAL
WHITE LINE DATA
CURVATURE CALCULATION UNIT
LATERAL POSITION F/B GAIN MULTIPLICATION CALCULATION UNIT
VEHICLE SPEED
TURN SIGNAL SW
43

FIG. 4

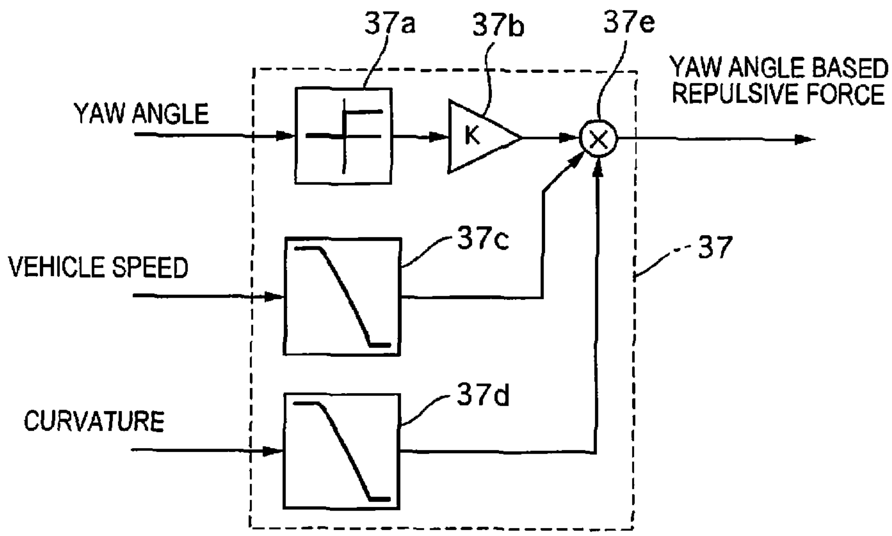

37a
37b
37e
YAW ANGLE BASED REPULSIVE FORCE
YAW ANGLE
K
VEHICLE SPEED
37c
37
CURVATURE
37d

FIG. 5

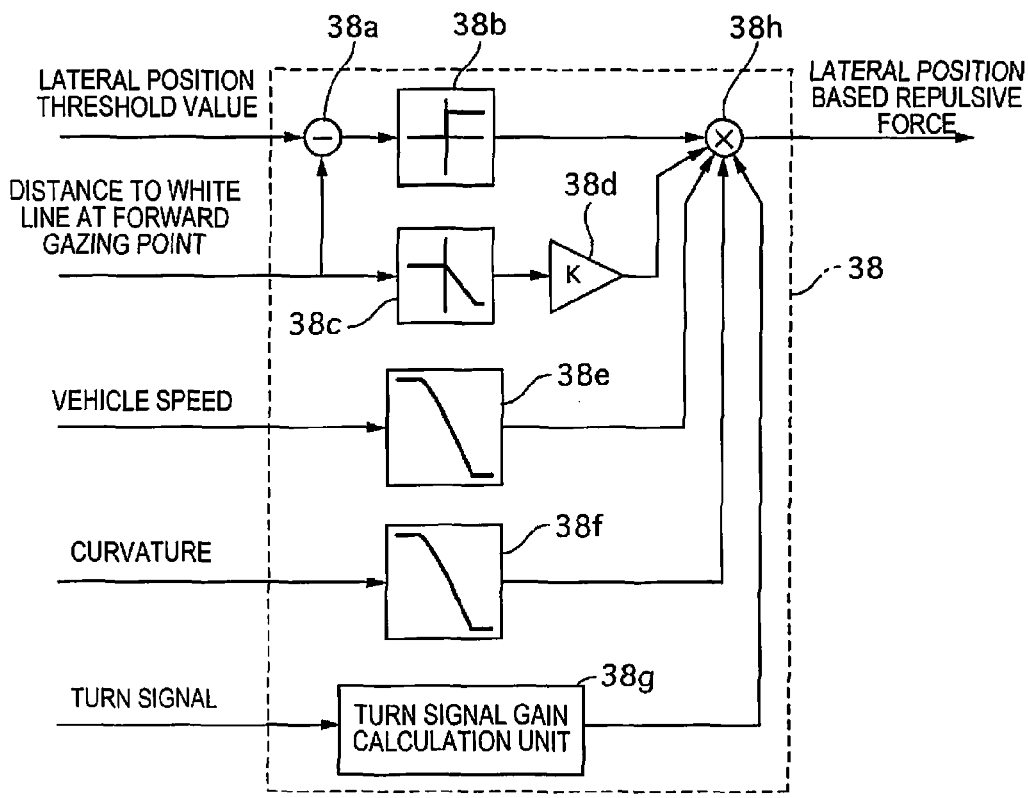

38a
38b
38h
LATERAL POSITION THRESHOLD VALUE
LATERAL POSITION BASED REPULSIVE FORCE
DISTANCE TO WHITE LINE AT FORWARD GAZING POINT
38d
K
38
38c
VEHICLE SPEED
38e
CURVATURE
38f
TURN SIGNAL
38g
TURN SIGNAL GAIN CALCULATION UNIT

FIG. 6

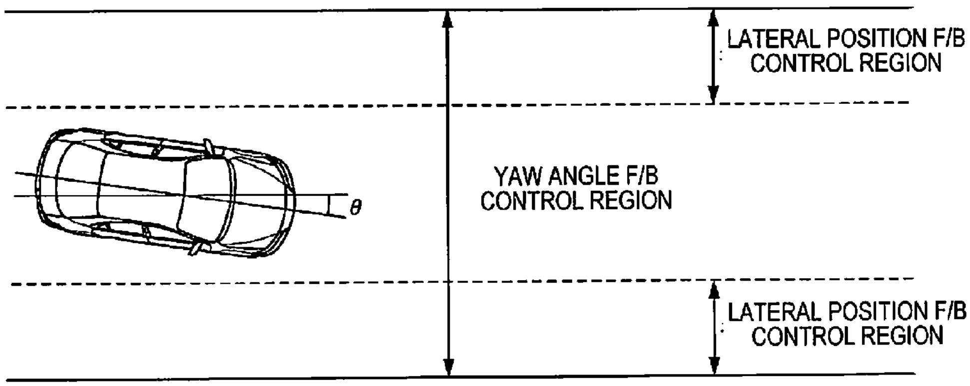


FIG. 7

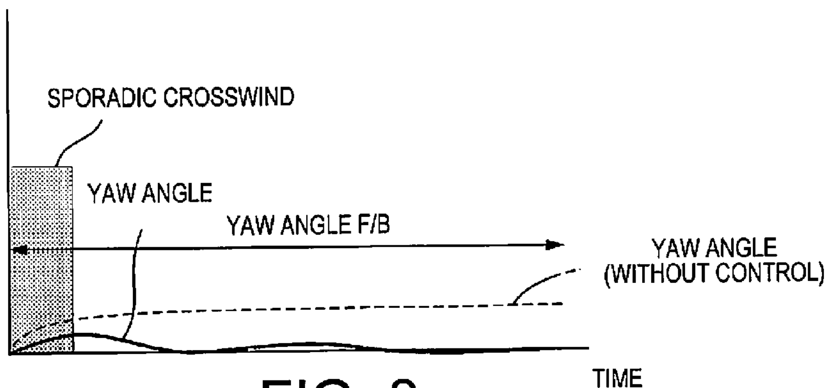


FIG. 8

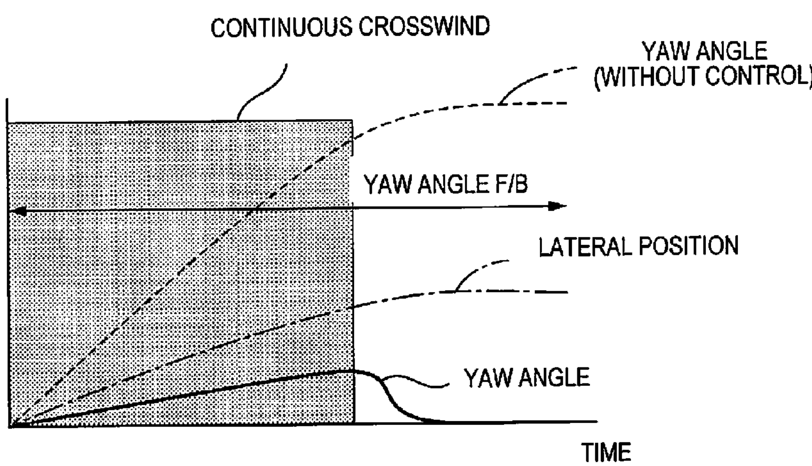


FIG. 9

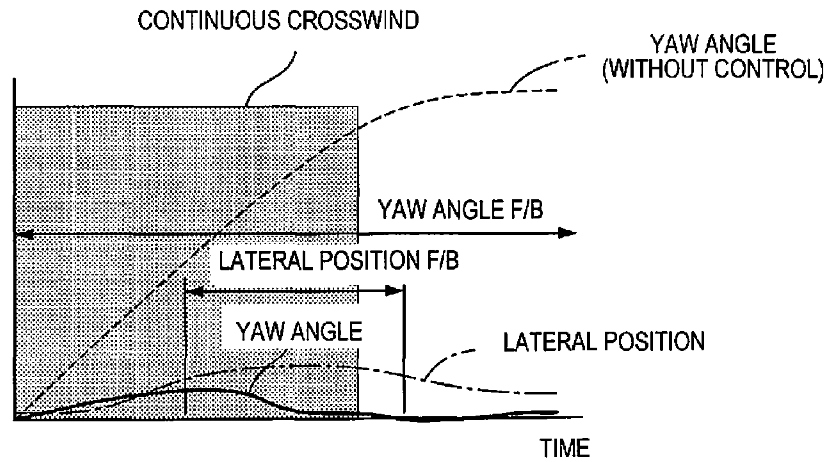


FIG. 10

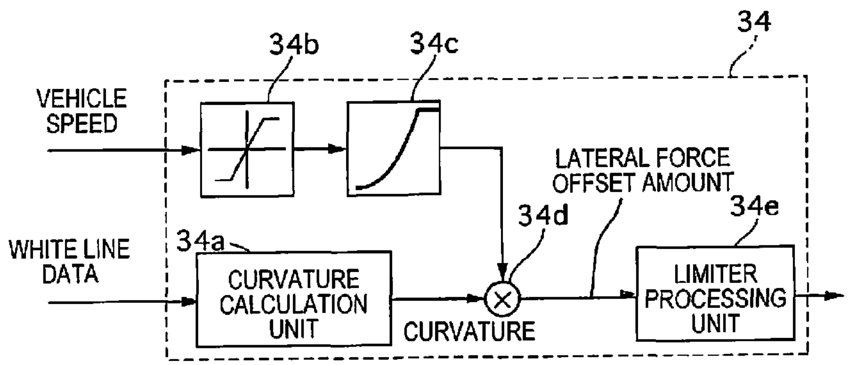


FIG. 11

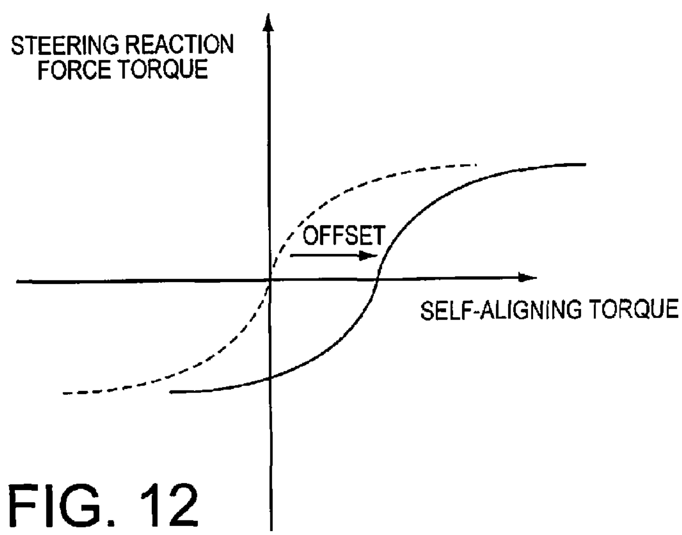


FIG. 12

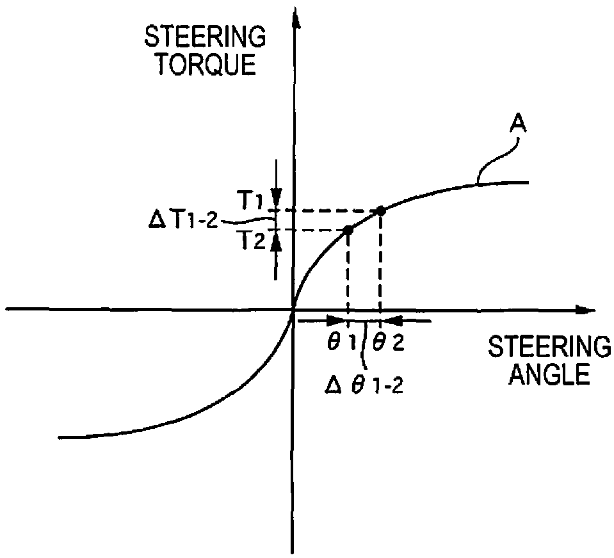

STEERING
TORQUE
A
T1
ΔT1-2
T2
θ1
θ2
Δθ1-2
STEERING
ANGLE

FIG. 13

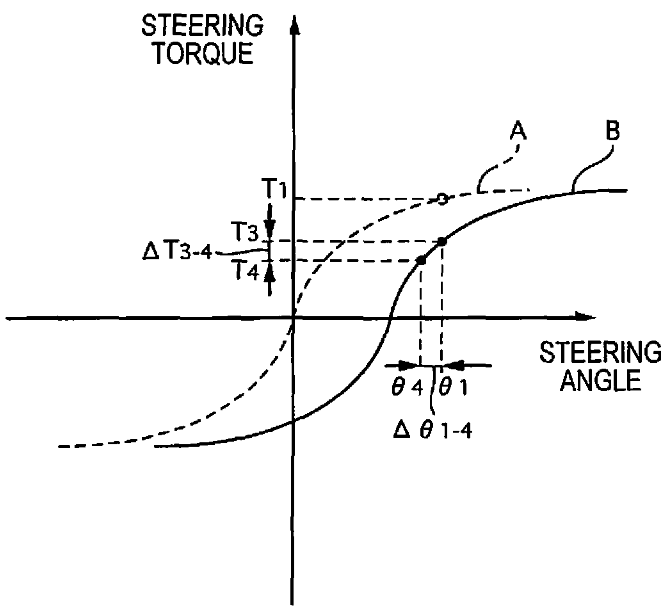

STEERING
TORQUE
A
B
T1
T3
ΔT3-4
T4
STEERING
ANGLE
θ4
θ1
Δθ1-4

FIG. 14

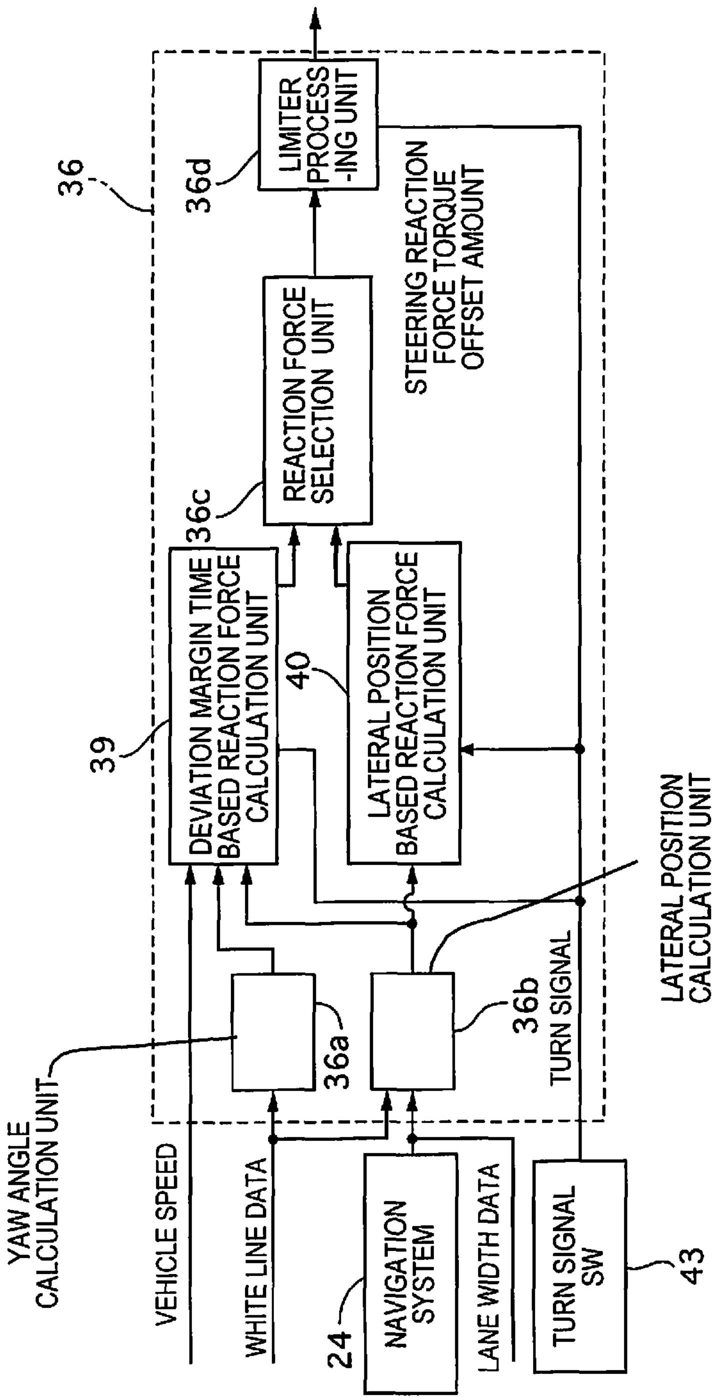

36
36d
LIMITER PROCESS-ING UNIT
REACTION FORCE SELECTION UNIT
STEERING REACTION FORCE TORQUE OFFSET AMOUNT
36c
39
DEVIATION MARGIN TIME BASED REACTION FORCE CALCULATION UNIT
40
LATERAL POSITION BASED REACTION FORCE CALCULATION UNIT
LATERAL POSITION CALCULATION UNIT
YAW ANGLE CALCULATION UNIT
36a
36b
TURN SIGNAL
VEHICLE SPEED
WHITE LINE DATA
24
NAVIGATION SYSTEM
LANE WIDTH DATA
TURN SIGNAL SW
43

FIG. 15

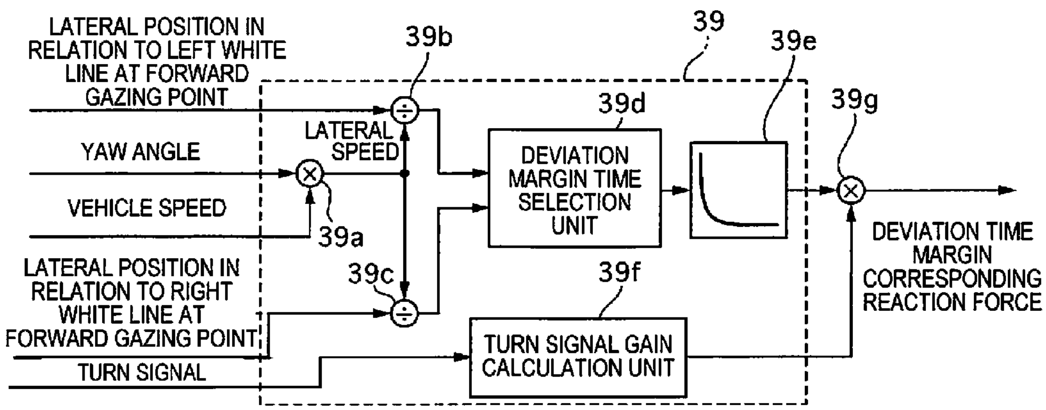

LATERAL POSITION IN RELATION TO LEFT WHITE LINE AT FORWARD GAZING POINT
YAW ANGLE
VEHICLE SPEED
LATERAL POSITION IN RELATION TO RIGHT WHITE LINE AT FORWARD GAZING POINT
TURN SIGNAL
39b
39
39e
39d
39g
LATERAL SPEED
DEVIATION MARGIN TIME SELECTION UNIT
39a
39c
39f
TURN SIGNAL GAIN CALCULATION UNIT
DEVIATION TIME MARGIN CORRESPONDING REACTION FORCE

FIG. 16

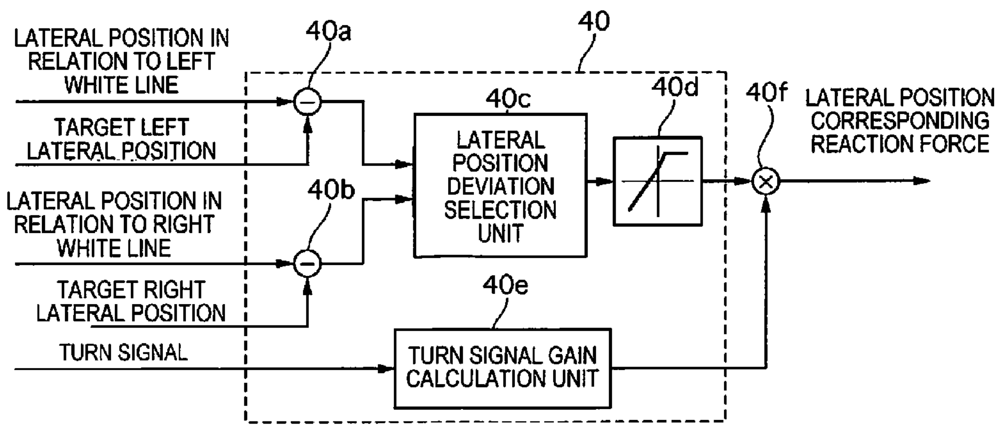

LATERAL POSITION IN RELATION TO LEFT WHITE LINE
TARGET LEFT LATERAL POSITION
LATERAL POSITION IN RELATION TO RIGHT WHITE LINE
TARGET RIGHT LATERAL POSITION
TURN SIGNAL
40a
40
40c
40d
40f
40b
40e
LATERAL POSITION DEVIATION SELECTION UNIT
TURN SIGNAL GAIN CALCULATION UNIT
LATERAL POSITION CORRESPONDING REACTION FORCE

FIG. 17

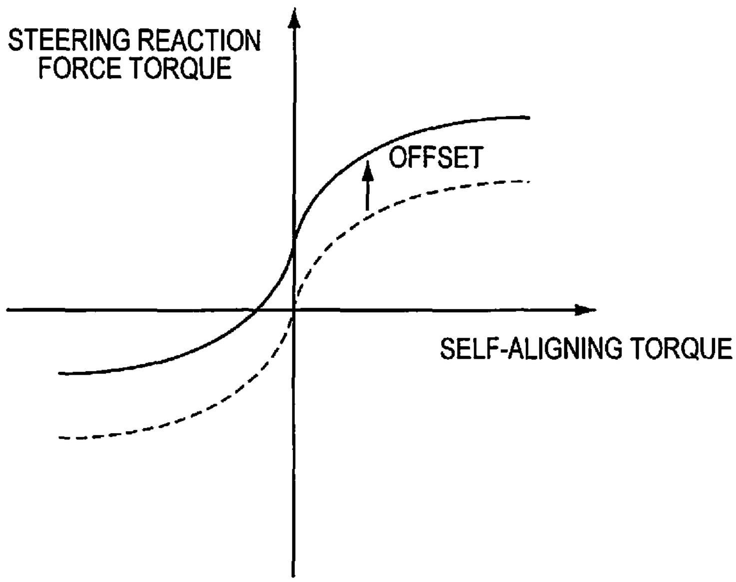

STEERING REACTION
FORCE TORQUE
OFFSET
SELF-ALIGNING TORQUE

FIG. 18

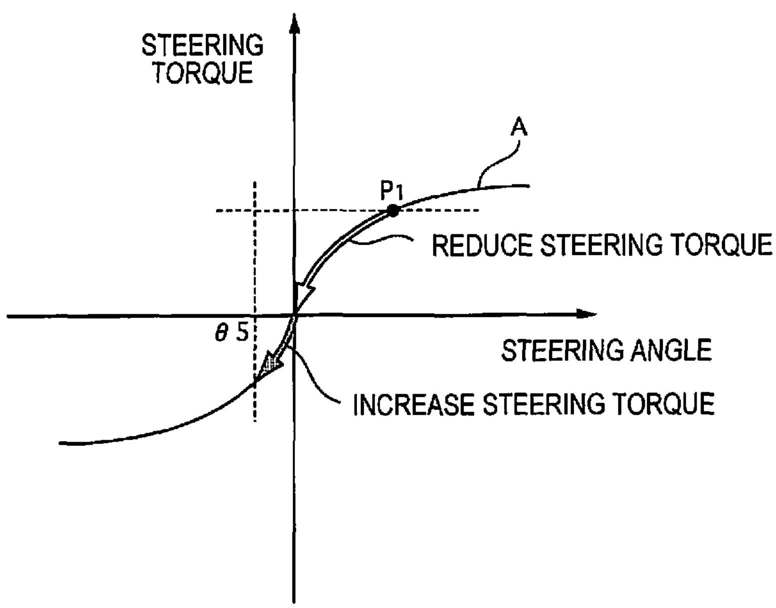

STEERING
TORQUE
A
P1
REDUCE STEERING TORQUE
θ 5
STEERING ANGLE
INCREASE STEERING TORQUE

FIG. 19

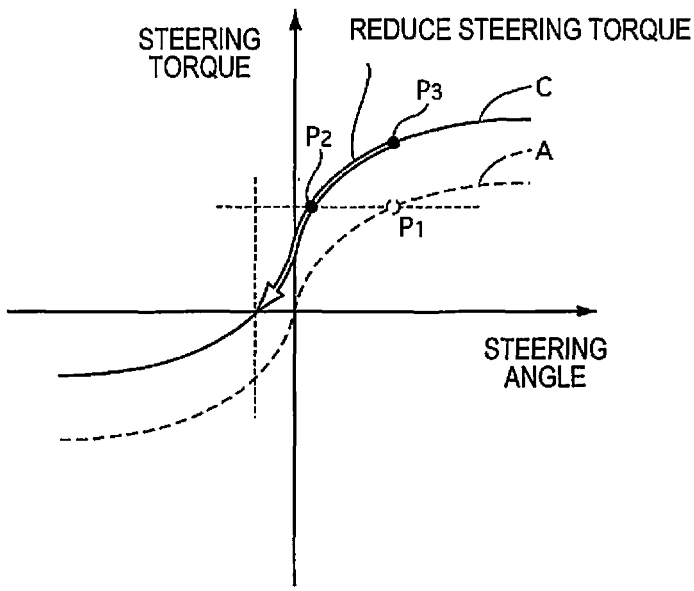

STEERING TORQUE
REDUCE STEERING TORQUE
P3
C
P2
A
P1
STEERING ANGLE

FIG. 20

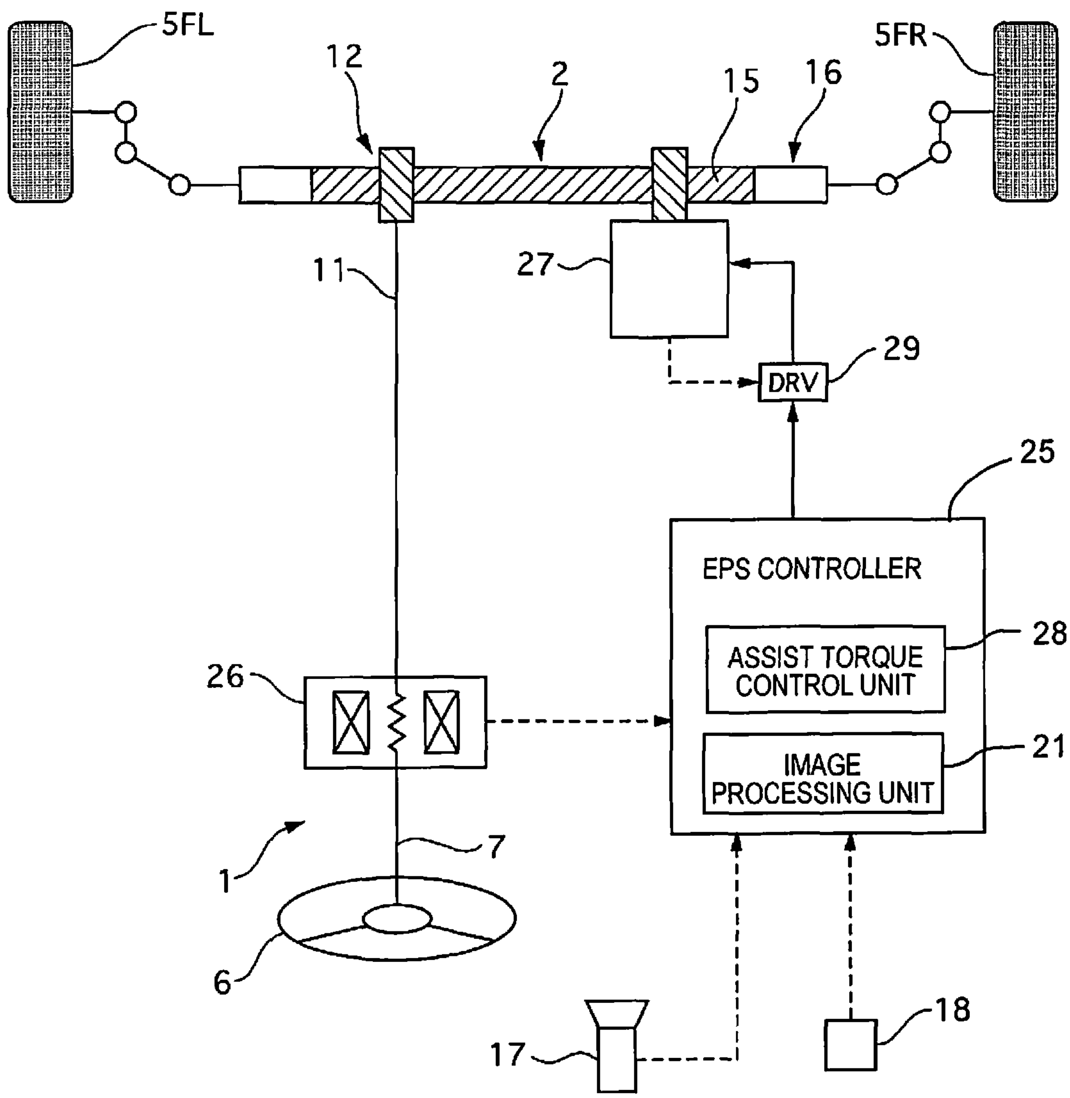
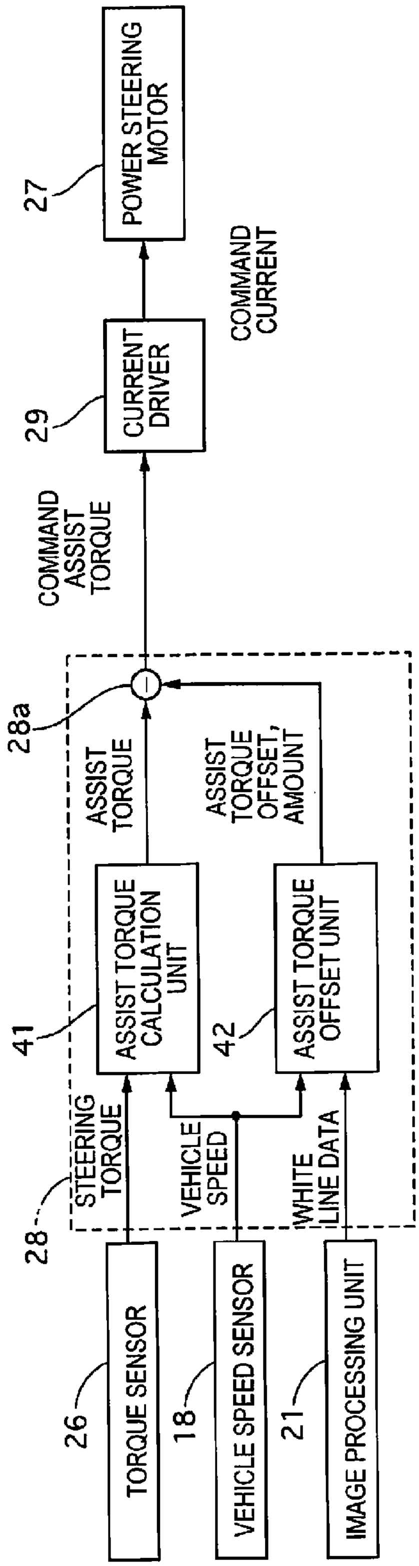

5FL
12
2
15
16
5FR
11
27
29
DRV
25
EPS CONTROLLER
ASSIST TORQUE CONTROL UNIT
28
IMAGE PROCESSING UNIT
21
26
1
7
6
17
18

FIG. 21



POWER STEERING MOTOR
27
CURRENT DRIVER
29
COMMAND CURRENT
COMMAND ASSIST TORQUE
28a
ASSIST TORQUE
ASSIST TORQUE OFFSET, AMOUNT
ASSIST TORQUE CALCULATION UNIT
41
ASSIST TORQUE OFFSET UNIT
42
STEERING TORQUE
VEHICLE SPEED
WHITE LINE DATA
28
TORQUE SENSOR
26
VEHICLE SPEED SENSOR
18
IMAGE PROCESSING UNIT
21

FIG. 22

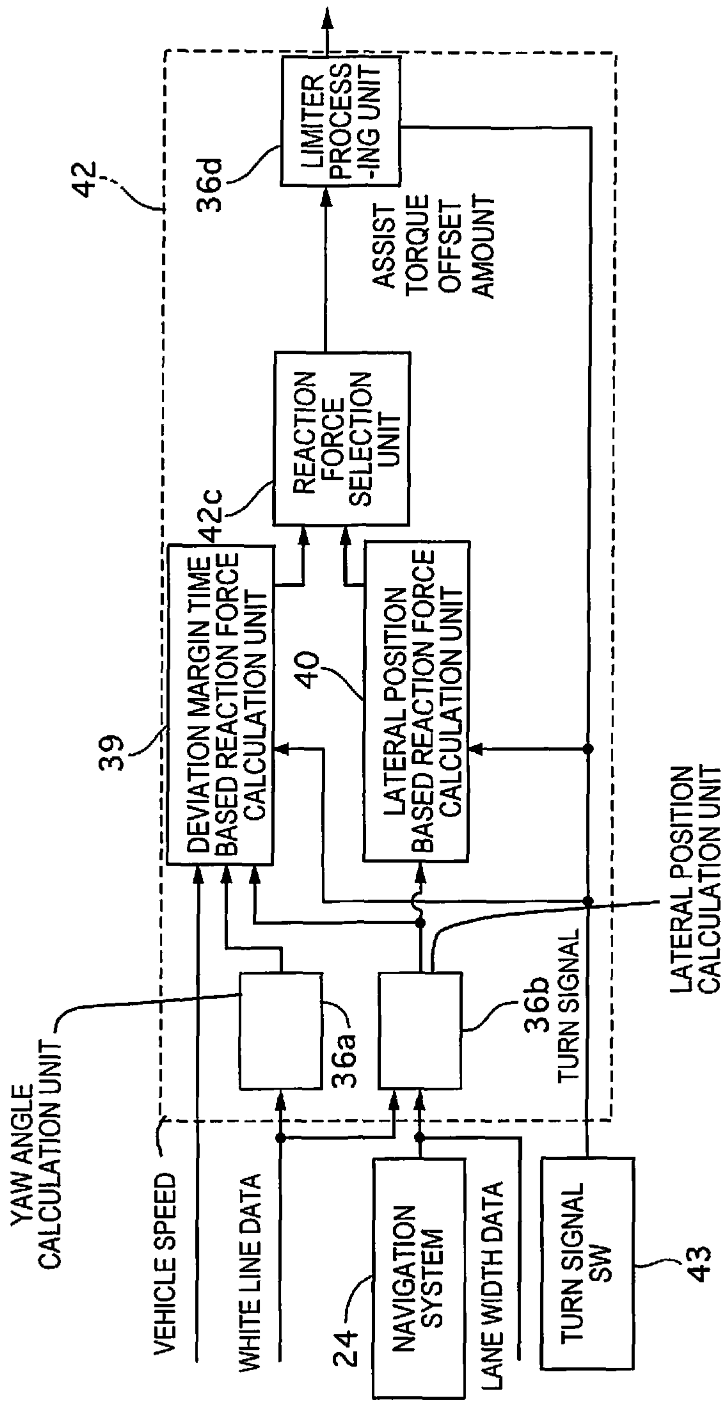

42
36d
LIMITER PROCESS -ING UNIT
ASSIST TORQUE OFFSET AMOUNT
42c
REACTION FORCE SELECTION UNIT
39
DEVIATION MARGIN TIME BASED REACTION FORCE CALCULATION UNIT
40
LATERAL POSITION BASED REACTION FORCE CALCULATION UNIT
LATERAL POSITION CALCULATION UNIT
YAW ANGLE CALCULATION UNIT
36a
36b
TURN SIGNAL
VEHICLE SPEED
WHITE LINE DATA
24
NAVIGATION SYSTEM
LANE WIDTH DATA
TURN SIGNAL SW
43

FIG. 23

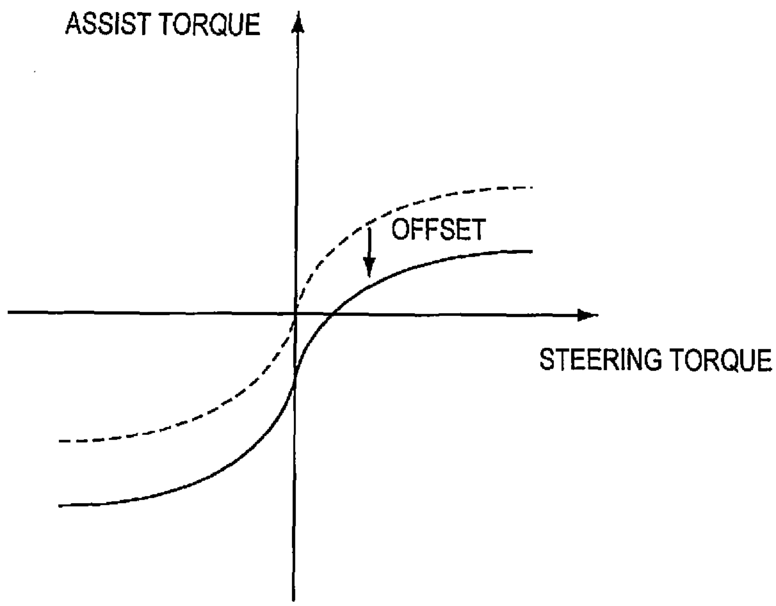


FIG. 24

STEERING CONTROL DEVICE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a U.S. National stage application of International Application No. PCT/JP2013/082718, filed Dec. 5, 2013, which claims priority to Japanese Patent Application No. 2013-002376 filed in Japan on Jan. 10, 2013.

BACKGROUND

1. Field of the Invention

The present invention relates to a steering control device.

2. Background Information

Japanese Laid Open Patent Application No. 2008-120288 discloses a technique for suppressing the control amount of a lane maintenance control, when a turn signal is operated during a lane maintenance control that applies a steering force so that a vehicle will travel in the vicinity of the center of the traveling lane.

SUMMARY

In the prior art described above, there is a problem that the steering reaction force increases rapidly when the suppression of the control amount is released at the end of the turn signal operation, imparting discomfort to the driver. The object of the present invention is to provide a steering control device that is capable of reducing discomfort when releasing the suppression of the control amount.

In the present invention, a steering reaction force characteristic is set to coordinates, of which the coordinate axes are the self-aligning torque and the steering reaction force, so that the self-aligning torque increases as the steering reaction force increases, and upon applying a steering reaction force corresponding to the self-aligning torque to the steering unit based on the steering reaction force characteristic to offset the steering reaction force characteristic at the coordinates more in a direction in which the absolute value of the steering reaction force increases as the lateral position of a host vehicle becomes closer to a white line, the offset of the steering reaction force characteristic is suppressed when a turn signal operation is started while the suppression of the offset of the steering reaction force characteristic is released when a turn signal operation is ended so that the absolute value of the increase gradient when releasing the suppression of the offset becomes smaller than the absolute value of the decrease gradient when suppressing the offset.

Therefore, since the offset of the steering reaction force characteristic is gradually restored when the turn signal operation is ended, a rapid increase in the steering reaction force can be suppressed, and the discomfort imparted to the driver can be reduced.

BRIEF DESCRIPTION OF THE DRAWINGS

Referring now to the attached drawings which form a part of this original disclosure.

FIG. **1** is a system view illustrating the steering system of a vehicle of the first embodiment.

FIG. **2** is a control block view of the turn control unit **19**.

FIG. **3** is a control block view of a steering reaction force control unit **20**.

FIG. **4** is a control block view of a disturbance suppression command turning angle calculation unit **32**.

FIG. **5** is a control block view of a yaw angle based repulsive force calculation unit **37**.

FIG. **6** is a control block view of a lateral position based repulsive force calculation unit **38**.

FIG. **7** is a view illustrating a control region of the yaw angle F/B control and the lateral position F/B control.

FIG. **8** is a time chart illustrating the yaw angle change when a vehicle traveling a straight road of a highway receives a sporadic crosswind.

FIG. **9** is a time chart illustrating the yaw angle change and the lateral position change when the lateral position F/B control is not executed when a vehicle traveling on a straight road of a highway receives a continuous crosswind.

FIG. **10** is a time chart illustrating the yaw angle change and the lateral position change when the lateral position F/B control is executed when a vehicle traveling on a straight road of a highway receives a continuous crosswind.

FIG. **11** is a control block view of a lateral force offset unit **34**.

FIG. **12** is a view illustrating a state in which a steering reaction force characteristic, representing the steering reaction force torque corresponding to a self-aligning torque, is offset in the same direction as the self-aligning torque.

FIG. **13** is a characteristic view illustrating the relationship between the steering angle of the steering wheel and the steering torque of the driver.

FIG. **14** is a view illustrating a state in which a characteristic illustrating the relationship between the steering angle of the steering wheel and the steering torque of the driver has been changed by offsetting the steering reaction force characteristic, representing the steering reaction force torque corresponding to the self-aligning torque, in the same direction as the self-aligning torque.

FIG. **15** is a control block view of a steering reaction force torque offset unit **36**.

FIG. **16** is a control block view of a deviation margin time based reaction force calculation unit **39**.

FIG. **17** is a control block view of a lateral position based reaction force calculation unit **40**.

FIG. **18** is a view illustrating a state in which the steering reaction force characteristic, representing the steering reaction force torque corresponding to the self-aligning torque, is offset in a direction in which the absolute value of the steering reaction force torque becomes larger.

FIG. **19** is a characteristic view illustrating the relationship between the steering angle of the steering wheel and the steering torque of the driver.

FIG. **20** is a view illustrating a state in which the characteristic illustrating the relationship between the steering angle of the steering wheel and the steering torque of the driver has been changed by offsetting the steering reaction force characteristic, representing the steering reaction force torque corresponding to the self-aligning torque, in a direction in which the absolute value of the steering reaction force torque becomes larger.

FIG. **21** is a system view illustrating the steering system of a vehicle of the second embodiment.

FIG. **22** is a control block view of the assist torque control unit **28**.

FIG. **23** is a control block view of an assist torque offset unit **42**.

FIG. **24** is a view illustrating a state in which the assist torque characteristic, representing the assist torque corresponding to the steering torque, is offset in a direction in which the absolute value of the assist torque becomes smaller.

DETAILED DESCRIPTION OF THE EMBODIMENTS

FIG. **1** is a system view illustrating a steering system of a vehicle of the first embodiment.

The steering device of the first embodiment is mainly configured by a steering unit **1**, a turning unit **2**, a backup clutch **3**, and an SBW controller **4**, and the device employs a steer-by-wire (SBW) system in which the steering unit **1**, which receives steering input from a driver and the turning unit **2**, which turns a left and a right front wheel (the turning wheels) **5**FL, **5**FR are mechanically detached.

The steering unit **1** is provided with a steering wheel **6**, a column shaft **7**, a reaction force motor **8**, and a steering angle sensor **9**. The column shaft **7** rotates integrally with the steering wheel **6**. The reaction force motor **8** is, for example, a brushless motor, and a coaxial motor in which the output shaft is coaxial with the column shaft **7** outputs a steering reaction force torque to the column shaft **7** in response to a command from the SBW controller **4**. The steering angle sensor **9** detects the absolute rotation angle of the column shaft **7**, that is, the steering angle of the steering wheel **6**.

The turning unit **2** is provided with a pinion shaft **11**, a steering gear **12**, a turning motor **13**, and a turning angle sensor **14**. The steering gear **12** is a rack-and-pinion-type steering gear, which turns the front wheels **5**L, **5**R in response to the rotation of the pinion shaft **11**. The turning motor **13** is, for example, a brushless motor, in which the output shaft is connected to a rack gear **15** via an unillustrated decelerator, and this motor outputs a turning torque for turning the front wheels **5** to a rack **16** in response to a command from the SBW controller **4**. The turning angle sensor **14** detects the absolute rotation angle of the turning motor **13**. Since there is an always uniquely determined correlation between the rotation angle of the turning motor **13** and the turning angle of the front wheels **5**, the turning angle of the front wheels **5** can be detected based on the rotation angle of the turning motor **13**. Herein below, unless specifically described, the turning angle of the front wheels **5** shall be that which is calculated based on the rotation angle of the turning motor **13**. The backup clutch **3** is provided between the column shaft **7** of the steering unit **1** and the pinion shaft **11** of the turning unit **2**, and the steering unit **1** and the turning unit **2** are mechanically detached by a release; the steering unit **1** and the turning unit **2** are mechanically connected by the fastening thereof.

In addition to the steering angle sensor **9** and the turning angle sensor **14** described above, the vehicle speed (the vehicle body speed) detected by an image of the traveling path in front of the host vehicle captured by a camera **17** and a vehicle speed sensor **18** are input into the SBW controller **4**. The SBW controller **4** comprises a turn control unit **19** for controlling the turning angle of the front wheels **5**FL, **5**FR, a steering reaction force control unit **20** for controlling the steering reaction force torque applied to the column shaft **7**, and an image processing unit **21**. The turn control unit **19** generates a command turning angle based on each piece of input information and outputs the generated command turning angle to a current driver **22**. The current driver **22** controls the command current to the turning motor **13** by an angle feedback for matching the actual turning angle detected by the turning angle sensor **14** with the command turning angle. The steering reaction force control unit **20** generates a command steering reaction force torque based on each piece of input information and outputs the generated command steering reaction force torque to a current driver **23**. The current driver **23** controls the command current to the reaction force motor **8** by a torque feedback for matching the actual steering reaction force torque that is inferred from the current value of the reaction force motor **8** with the command steering reaction force torque. The image processing unit **21** recognizes a traveling lane left and right white lines (the traveling path dividing lines) by image processing, such as by edge extraction from an image of a traveling path in front of a host vehicle captured by the camera **17**. In addition, when the SBW system fails, the SBW controller **4** fastens the backup clutch **3** and mechanically couples the steering unit **1** and the turning unit **2**, allowing the rack **16** to move in the axial direction by steering the steering wheel **6**. At this time, a control corresponding to an electric power steering system for assisting the steering force of the driver by an assist torque of the turning motor **13** can be executed. The SBW system described above may be a redundant system provided with a plurality of each sensor, each controller, and each motor. Additionally, the turn control unit **19** and the steering reaction force control unit **20** may be separate bodies.

In the first embodiment, stability control and corrective steering reduction control are executed with the aim to reduce the corrective steering amount and to reduce the steering load of the driver. Stability control aims to improve the safety of a vehicle with respect to a disturbance (crosswind, uneven road surfaces, ruts, road surface cants, and etc.), and performs two feedback (F/B) controls.

1. Yaw Angle F/B Control

The yaw angle generated by a disturbance is reduced by correcting the turning angle in accordance with the yaw angle, which is the angle between the white line and the host vehicle traveling direction.

2. Lateral Position F/B Control

The lateral position change, which is the integrated value of the yaw angles generated by a disturbance, is reduced by correcting the turning angle in accordance with the distance to the white line (the lateral position).

The corrective steering reduction control aims to improve the safety of a vehicle with respect to the steering input from the driver and performs three reaction force offset controls.

1. Reaction Force Offset Control Corresponding to the Lateral Position

The steering reaction force characteristic corresponding to the self-aligning torque is offset in a direction in which the absolute value of the steering reaction force becomes larger in accordance with the lateral position in order to suppress the sign of the steering torque from being inverted when a driver performs corrective steering that straddles the steering angle neutral position.

2. Reaction Offset Control Corresponding to the Deviation Margin Time.

The steering reaction force characteristic corresponding to the self-aligning torque is offset in a direction in which the absolute value of the steering reaction force becomes larger in accordance with the deviation margin time (the time required to reach the white line) in order to suppress the sign of the steering torque from being inverted when a driver performs corrective steering that straddles the steering angle neutral position.

3. Reaction Force Offset Control Corresponding to the Curvature.

The steering reaction force characteristic corresponding to the self-aligning torque is offset in the same coding direction as the self-aligning torque in accordance with the curvature of the white line in order to reduce the steering retention force of the driver and to suppress a change in the steering retention angle with respect to a change in the steering retention force when turning.

Turn Control Unit

FIG. **2** is a control block view of the turn control unit **19**. The SBW command turning angle calculation unit **31** calculates an SBW command turning angle based on the steering angle and the vehicle speed. The disturbance suppression command turning angle calculation unit **32** calculates a disturbance suppression command turning angle for correcting the SBW command turning angle during stability control, based on the vehicle speed and the white line information. The details of the disturbance suppression command turning angle calculation unit **32** will be described below. The adder **19***a* outputs a value obtained by adding the SBW command turning angle and the disturbance suppression command turning angle to the current driver **22** as the final command turning angle.

Steering Reaction Force Control Unit

FIG. **3** is a control block view of a steering reaction force control unit **20**. The lateral force calculation unit **33** calculates a tire lateral force by referencing a steering angle-lateral force conversion map representing the relationship between the steering angle and the tire lateral force per vehicle speed in a conventional steering device, which have been obtained by experimentation or other means beforehand, based on the steering angle and the vehicle speed. The steering angle-lateral force conversion map has a characteristic in which the tire lateral force increases as the steering angle increases; the change amount of the tire lateral force with respect to the change amount of the steering angle is larger when the steering angle is small, as compared to when large; and the tire lateral force becomes smaller as the vehicle speed increases. The lateral force offset unit **34** calculates a lateral force offset amount for offsetting the steering reaction force characteristic in a reaction force offset control corresponding to the curvature, based on vehicle speed and white line information. The details of the lateral force offset unit **34** will be described below. The subtracter **20***a* subtracts the lateral force offset amount from the tire lateral force. The SAT calculation unit **35** calculates a steering reaction force torque that is generated by the tire lateral force by referencing a lateral force-steering reaction force torque conversion map, representing the relationship between the tire lateral force and the steering reaction force torque in a conventional steering device obtained by experimentation or other means beforehand, based on vehicle speed and the tire lateral force after an offset by the lateral force offset amount. The tire lateral force-steering reaction force torque conversion map has a characteristic in which the steering reaction force torque is larger as the tire lateral force increases; the change amount of the steering reaction force torque with respect to the change amount of the tire lateral force is larger when the tire lateral force is small, as compared to when large; and the steering reaction force torque becomes smaller as the vehicle speed increases. This characteristic simulates a reaction force that is generated in the steering wheel by the self-aligning torque of wheels trying to return to a straight state, which is generated by the road surface reaction force in a conventional steering device.

The adder **20***b* adds a steering reaction force torque component (a spring item, a viscous item, an inertia item) corresponding to the steering reaction force torque and the steering characteristic. The spring item is a component that is proportional to the steering angle and is calculated by multiplying a predetermined gain and the steering angle. The viscous item is a component proportional to the steering angular velocity and is calculated by multiplying a predetermined gain and the steering angular velocity. The inertia item is a component that is proportional to the steering angular acceleration and is calculated by multiplying a predetermined gain and the steering angular acceleration. The steering reaction force torque offset unit **36** calculates a steering reaction force torque offset amount for offsetting the steering reaction force characteristic in a reaction force offset control corresponding to the lateral position or the deviation margin time, based on the vehicle speed and the image of a traveling path in front of the host vehicle. The details of the steering reaction force torque offset unit **36** will be described below. The adder **20***c* outputs a value obtained by adding the steering reaction force torque, after adding a steering reaction force torque component corresponding to the steering characteristic, and the steering torque offset amount to the current driver **23** as the final command steering reaction force torque.

Disturbance Suppression Command Turning Angle Calculation Unit

FIG. **4** is a control block view of a disturbance suppression command turning angle calculation unit **32**. The yaw angle calculation unit **32***a* calculates the yaw angle, which is an angle between the white line in a forward gazing point and the host vehicle traveling direction. The yaw angle at the forward gazing point shall be the angle formed between the white line after a predetermined time (for example, 0.5 seconds) and the host vehicle traveling direction. Easily and precisely detecting the yaw angle is possible by calculating the yaw angle based on an image of the traveling path captured by the camera **17**. The curvature calculation unit **32***b* calculates the curvature of the white line at the forward gazing point. The lateral position calculation unit **32***c* calculates the distance to the white line at the forward gazing point. The yaw angle based repulsive force calculation unit **37** calculates the repulsive force of the vehicle for reducing the yaw angle that is generated by a disturbance in a yaw angle F/B control, based on the yaw angle, the curvature, and the vehicle speed. The details of the yaw angle based repulsive force calculation unit **37** will be described below.

The lateral position based repulsive force calculation unit **38** calculates the repulsive force of the vehicle for reducing the lateral position change that is generated by a disturbance in a lateral position F/B control, based on the yaw angle, the curvature, the vehicle speed, the distance to the white line at the forward gazing point, and a turn signal from the turn signal switch **43**. The details of the lateral position based repulsive force calculation unit **38** will be described below. The adder **32***d* adds a repulsive force corresponding to the yaw angle and a repulsive force corresponding to the lateral position and calculates the lateral direction repulsive force. The target yaw moment calculation unit **32***e* calculates a target yaw moment based on the lateral direction repulsive force, the wheelbase (the distance between the axles), the rear wheel axle load, and the front wheel axle load. Specifically, a value multiplying the ratio of the rear wheel axle load, with respect to the vehicle weight (the front wheel axle load+the rear wheel axle load), and the wheelbase, with respect to the lateral direction repulsive force, shall be the target yaw moment. The target yaw acceleration calculation unit **32***f* calculates the target yaw acceleration by multiplying a yaw inertia moment coefficient and the target yaw moment. The target yaw rate calculation unit **32***g* calculates a target yaw rate by multiplying the headway time and the target yaw acceleration.

The turning angle command calculation unit **32***h* calculates the disturbance suppression command turning angle δ_{st}* by referencing the following formula, based on the target yaw rate ϕ*, the wheelbase WHEEL_BASE, the vehicle speed V, and the characteristic velocity of the vehicle vCh. Here, the characteristic velocity of the vehicle V_{Ch} is a parameter in the well-known "Ackerman Equation," representing the self-steering characteristics of the vehicle.

$$\delta_{st}*=(\phi*\text{WHEEL\_BASE}(1+(V/vCh)2)180)/(V\times M\_PI)$$

M_PI is a predetermined coefficient.

The limiter processing unit **32***i* limits the maximum value and the upper limit of the change rate of the disturbance suppression command turning angle δ_{st}*. In a conventional steering device (in which the steering unit and the turning unit are mechanically connected), when the steering angle of the steering wheel **6** in an angle range of the play near the neutral position (for example, 3° to the left and right), the maximum value shall be the turning angle range of the front wheels **5**FL, **5**FR corresponding to the range of the play (for example, 0.2° to the left and right). The limiter processing unit **32***i* limits the change rate of the disturbance suppression command turning angle δ_{st}* in accordance with the turn signal. Specifically, the absolute value of the increase gradient when the turn signal is switched from ON to OFF is made smaller than the absolute value of the decrease gradient when the turn signal is switched from OFF to ON.

FIG. **5** is a control block view of the yaw angle based repulsive force calculation unit **37**. The upper and lower limiter **37***a* executes an upper and lower limiter process on the yaw angle. When the yaw angle is a positive value (the yaw angle is positive when the white line intersects a line extending in the host vehicle traveling direction), the upper and lower limiter sets the value to be equal to or greater than a predetermined value that is capable of suppressing the disturbance, and less than a value when the vehicle will vibrate as well as a value that is generated by the steering of the driver (for example, 1°), and sets the value to be 0 when the yaw angle is negative. The yaw angle F/B gain multiplication unit **37***b* multiplies a yaw angle F/B gain and the yaw angle after the limiter processing. The yaw angle F/B gain shall be equal to or greater than a predetermined value that will avoid a shortage in the control amount while securing responsiveness, and less than a value when the vehicle will vibrate as well as a value at which the driver will feel a misalignment in the neutral positions of the steering angle and the turning angle.

The vehicle speed correction gain multiplication unit **37***c* multiplies the vehicle speed correction gain and the vehicle speed. The vehicle speed correction gain shall have a characteristic that the maximum value is within the range of 0-70 km/h, gradually decreasing within the range of 70-130 km/h, and becoming the minimum value (0) within the range of equal to or greater than 130 km/h. The curvature correction gain multiplication unit **37***d* multiplies the curvature correction gain and the curvature. The curvature correction gain shall have a characteristic of becoming smaller as the curvature increases, and an upper limit and a lower limit (0) are set thereon. The multiplier **37***e* multiplies each of the outputs from the yaw angle F/B gain multiplication unit **37***b*, the vehicle speed correction gain multiplication unit **37***c*, and the curvature correction gain multiplication unit **37***d* to determine a repulsive force corresponding to the yaw angle.

FIG. **6** is a control block view of a lateral position based repulsive force calculation unit **38**. The subtracter **38***a* determines a lateral position deviation by subtracting the distance to the white line at the forward gazing point from a lateral position threshold value that has been set beforehand (for example, 90 cm). The upper and lower limiter **38***b* executes an upper and lower limiter process on the lateral position deviation. The upper and lower limiter takes a predetermined positive value when the lateral position deviation is a positive value; this value is 0 when the lateral position deviation is a negative value. The distance correction gain multiplication unit **38***c* multiplies the distance correction gain and the distance to the white line at the forward gazing point. The distance correction gain shall have a characteristic taking the maximum value when the distance to the white line is equal to or less than a predetermined value and of becoming smaller as the distance becomes longer when exceeding the predetermined value and a lower limit is set thereon.

The lateral position F/B gain multiplication unit **38***d* multiplies the lateral position F/B gain and the distance to the white line after a correction has been made by the distance correction gain multiplication unit **38***c*. The lateral position F/B gain shall be equal to or greater than a predetermined value that will avoid a shortage in the control amount while securing responsiveness, and less than a value when the vehicle will vibrate as well as a value at which the driver will feel a misalignment in the neutral positions; this is also set to be a value that is less than the yaw angle F/B gain of the yaw angle F/B gain calculation unit **37***b*. The vehicle speed correction gain multiplication unit **38***e* multiplies the vehicle speed correction gain and the vehicle speed. The vehicle speed correction gain shall have a characteristic that the maximum value is within the range of 0-70 km/h, gradually decreasing within the range of 70-130 km/h, and becoming the minimum value (0) within the range of equal to or greater than 130 km/h. The curvature correction gain multiplication unit **38***f* multiplies the curvature correction gain to the curvature. The curvature correction gain shall have a characteristic of becoming smaller as the curvature increases, and an upper limit and a lower limit (0) are set thereon. The turn signal gain calculation unit **38***g* outputs 1 when the turn signal is OFF and outputs a value smaller than 1 (for example 0.2) when the turn signal is ON. The multiplier **38***h* multiplies each of the outputs from the lateral position F/B gain multiplication unit **38***d*, the vehicle speed correction gain multiplication unit **38***e*, the curvature correction gain multiplication unit **38***f*, and the turn signal gain calculation unit **38***g* to determine a repulsive force corresponding to the lateral position.

Stability Control Effect

In the first embodiment, a yaw angle F/B control for reducing the yaw angle generated by a disturbance and a lateral position F/B control for reducing the lateral position change, which is the integrated value of the yaw angles generated by the disturbance, are executed as stability control. The yaw angle F/B control is executed regardless of the lateral position when a yaw angle is generated, and the lateral position F/B control is executed when the distance to the white line becomes equal to or less than a predetermined lateral position threshold value (90 cm). That is, the vicinity of the center of the traveling lane becomes a dead zone for the lateral position F/B control. The control ranges of the two F/B controls are illustrated in FIG. **7**. ϕ is the yaw angle.

FIG. **8** is a time chart illustrating the yaw angle change when a vehicle traveling a straight road of a highway receives a sporadic crosswind, and the vehicle is assumed to be traveling in the vicinity of the center of the traveling lane. In the yaw angle F/B control, when the vehicle receives a sporadic crosswind and a yaw angle is generated, a repulsive force corresponding to the yaw angle is calculated, a disturbance suppression command turning angle for obtaining the repulsive force is determined, and the SBW command turning angle based on the steering angle and vehicle speed is corrected. When a vehicle travels along the traveling lane, especially on a straight road, the direction of the white line and the host vehicle traveling direction match, so the yaw angle will be zero. That is, in the yaw angle F/B control of the first embodiment, the yaw angle is assumed to be generated by a disturbance; therefore, enhancing the safety of the vehicle with respect to the disturbance, especially while traveling straight by reducing the yaw angle, is possible, and reducing the corrective steering amount of the driver is possible.

Conventionally, as those that suppress the effect of a disturbance, such as a crosswind, to the vehicle behavior, that which applies a turning torque for disturbance suppression to the steering system is known in a conventional steering device, and that which applies a steering reaction force component that promotes turning for disturbance suppression is known in an SBW system. However, fluctuation in the steering reaction force is generated in these conventional steering devices, imparting discomfort to the driver. In contrast, in the stability control comprising the yaw angle F/B control of the first embodiment, by focusing attention on the point that the steering wheel **6** and the front wheels **5**L, **5**R can be independently controlled, which is a characteristic of an SBW system in which the steering wheel **6** and the front wheels **5**L and **5**R are mechanically detached, the turning angle of the front wheels **5**L, **5**R are controlled based on a command turning angle that adds the SBW command turning angle corresponding to the steering angle and the vehicle speed and the disturbance suppression command turning angle corresponding to the yaw angle, while a tire lateral force is inferred based on the steering angle and vehicle speed, and the steering reaction force is controlled based on the command steering reaction force corresponding to the inferred tire lateral force and the vehicle speed. That is, since a turning angle for suppressing a disturbance is directly applied to the front wheels **5**L, **5**R, applying a steering reaction force component that promotes turning for disturbance suppression becomes unnecessary. Furthermore, by applying a steering reaction force corresponding to the tire lateral force inferred from the steering angle, fluctuation in the tire lateral force generated by turning for disturbance suppression will not be reflected on the steering reaction force; as a result, the discomfort imparted to the driver can be reduced. In a conventional SBW system, the tire lateral force is inferred from a rack axial force or the turning angle detected by a sensor, and a steering reaction force corresponding to the inferred tire lateral force is applied. Consequently, fluctuation in the tire lateral force generated by turning for disturbance suppression will always be reflected in the steering reaction force, creating a discomfort for the driver. In the first embodiment, only the tire lateral force that is generated by the steering of the driver is reflected on the steering reaction force, and the steering reaction force does not fluctuate due to turning for disturbance suppression; therefore, the discomfort imparted to the driver can be reduced.

Here, misalignment of the neutral positions of the steering angle and the turning angle becomes a problem when applying a turning angle for suppressing a disturbance directly to the front wheels **5**L, **5**R, but in the first embodiment, the disturbance suppression command turning angle is set to a turning angle range of the front wheels **5**FL, **5**FR (0.2° to the left and right) corresponding to the range of play, when the steering wheel **6** is in the angle range of the play in the vicinity of the steering angle neutral position (3° to the left and right) in a conventional steering device. The generation of yaw angle by disturbance is more notable when traveling straight than when turning; when traveling straight, the steering angle is positioned in the vicinity of the steering angle neutral position. In other words, since correcting the turning angle by the yaw angle F/B control is mostly executed in the vicinity of the steering angle neutral position, suppressing the discomfort that accompanies a neutral misalignment is possible by suppressing the neutral misalignment amount between the steering angle and the turning angle, which accompanies the application of the disturbance suppression command turning angle, in the range of the play of the steering. Additionally, since the disturbance suppression command turning angle is limited to the range of 0.2° to the left and right, the driver is able to change the traveling direction of the vehicle in the desired direction by the steering input, even during stability control. That is, since the correction amount of the turning angle by the disturbance suppression command turning angle is minute with respect to the change amount of the turning angle generated by the steering input of the driver, enhancing the safety of the vehicle with respect to a disturbance is possible without interfering with the steering by the driver.

Conventionally, a lane deviation prevention control that applies a yaw moment for avoiding the departure of the vehicle, when a traveling lane deviation tendency of the vehicle has been detected or a lane maintenance control that applies a yaw moment to the vehicle so that the vehicle will travel in the vicinity of the center of the traveling lane are known as those that control the lateral movement of the vehicle. However, a lane deviation prevention control is a control having a control intervention threshold, and the control is not actuated in the vicinity of the center of the traveling lane; therefore, the safety of the vehicle with respect to a disturbance cannot be secured. Also, since a control intervention takes place due to the threshold value even if the driver wants to pull the vehicle to the edge of the traveling lane, the driver will experience some difficulty. On the other hand, a lane maintenance control is a control having a target position (a target line), so that, while the safety of the vehicle with respect to disturbance can be secured, causing the vehicle to travel along a line that deviates from the target line is not possible. In addition, since the control will be released when the gripping force of the driver on the steering wheel is reduced due to a determination that a hands-off state exists, the driver will have to constantly grip the steering wheel at a force above a certain level; as a result, there is a large steering load on the driver. In contrast, the yaw angle F/B control of the first embodiment does not have a control intervention threshold; therefore, always securing safety with respect to disturbance with a seamless control is possible. Also, since the above does not have a target position, the driver is able to drive the vehicle in a desired line. Additionally, control will not be released even if the steering wheel **6** is lightly held, allowing for a reduction in the steering load of the driver.

FIG. **9** is a time chart illustrating the yaw angle change and the lateral position change when the lateral position F/B control is not executed when a vehicle traveling on a straight road of a highway receives a continuous crosswind, and the vehicle is assumed to be traveling in the vicinity of the center of the traveling lane. When a vehicle receives a continuous crosswind and a yaw angle is generated, the yaw angle will be reduced due to the yaw angle F/B control, but the vehicle will still be receiving a continuous disturbance and will be drifting. This is because the yaw angle F/B control is for reducing the yaw angle and will not correct the turning angle when the yaw angle is zero; therefore, directly reducing the lateral position change, which is the integrated value of the yaw angles that are generated due to a disturbance, is not possible. Indirectly suppressing the lateral position change (suppressing an increase in the integrated value of the yaw angles) is possible by making the repulsive force corresponding to the yaw angle a large value; however, since the maximum value of the disturbance suppression command turning angle is limited to 0.2° to the left and right so as not to impart discomfort to the driver, effectively suppressing the drifting of the vehicle only with yaw angle F/B control is difficult. Additionally, the yaw angle F/B gain for determining the repulsive force corresponding to the yaw angle is made to be as large a value as possible because converging the yaw angle before the driver notices the yaw angle change is necessary; however, since the vehicle will vibrate if this remains that way, the yaw angle that is multiplied by the yaw angle F/B gain is limited to equal to or less than the upper limit (1°) by the upper and lower limiter **37***a*. In other words, since the repulsive force corresponding to the yaw angle is a repulsive force corresponding to a yaw angle that is less than the actual yaw angle, this point also demonstrates that effectively suppressing the drifting of the vehicle only with yaw angle F/B control is difficult.

Therefore, in the stability control of the first embodiment, a lateral position F/B control is introduced to suppress the vehicle from drifting due to a steady disturbance. FIG. **10** is a time chart illustrating the yaw angle change and the lateral position change when the lateral position F/B control is executed when a vehicle traveling on a straight road of a highway receives a continuous crosswind; in the lateral position F/B control, when a vehicle traveling in the vicinity of the center of the traveling lane receives a continuous crosswind and drifts and the distance to the white line becomes equal to or less than a lateral position threshold, a repulsive force corresponding to the lateral position change (≈yaw angle integrated value) is calculated. In the disturbance suppression command turning angle calculation unit **32**, a disturbance suppression command turning angle based on the lateral repulsive force, which adds the repulsive force corresponding to the lateral position and the repulsive force corresponding to the yaw angle, is calculated, and the SBW command turning angle is corrected. That is, in the lateral position F/B control, the SBW command turning angle is corrected by a disturbance suppression command turning angle corresponding to the lateral position; as a result, directly reducing the lateral position change caused by a steady disturbance is possible, and the drifting of the vehicle can be suppressed. In other words, returning the traveling position of a vehicle conducting a yaw angle F/B control to the vicinity of the center of the traveling lane, which is a dead zone for the lateral position F/B control, is possible.

As described above, the stability control of the first embodiment reduces the yaw angle change due to a transient disturbance with the yaw angle F/B control and reduces the yaw angle integrated value (the lateral position change) due to a steady disturbance with the lateral position F/B control; as a result, the stability control is capable of enhancing the safety of the vehicle against both transient and steady disturbances. Furthermore, the stability control of the first embodiment limits the vehicle behavior that is generated by the control (the application of the disturbance suppression command turning angle) to a level that is not noticed by the driver and a level that will not interfere with the vehicle behavior change that is generated by the steering of the driver; this does not reflect the change in the self-aligning torque generated by the control on the steering reaction force and, thus, can be executed without the driver being aware that stability control is taking place. As a result, simulating the behavior of a vehicle as if having a vehicle body specification with excellent stability against disturbance is possible. The lateral position F/B gain for determining the repulsive force corresponding to the lateral position in the lateral position F/B control is set to a value less than the yaw angle F/B gain. As described above, the yaw angle F/B control must be highly responsive due to the necessity of converging the yaw angle before the driver feels a change in the yaw angle caused by a transient disturbance, whereas the lateral position F/B control does not require as much responsiveness as the yaw angle F/B control, because stopping the increase in the lateral position change is required and the lateral position takes time to change due to the accumulation of the yaw angle integrated value. In addition, this is because, if the lateral position F/B gain were to be increased, the control amount will change greatly according to the magnitude of the disturbance, and discomfort will be imparted on the driver.

Lateral Force Offset Unit

FIG. **11** is a control block view of a lateral force offset unit **34**. A curvature calculation unit **34***a* calculates the curvature of the white line at the forward gazing point. An upper and lower limiter **34***b* executes an upper and lower limiter process on the vehicle speed. An SAT gain calculating unit **34***c* calculates an SAT gain corresponding to the vehicle speed based on the vehicle speed after the limiter process. The SAT gains shall have a characteristic of becoming a larger gain as the vehicle speed increases, and an upper limit is set thereon. The multiplier **34***d* determines the lateral force offset amount by multiplying the curvature and the SAT gain. A limiter processing unit **34***e* limits the maximum value and the upper limit of the change rate of the lateral force offset amount. For example, the maximum value is 1,000 N, and the upper limit of the change rate is 600 N/s.

Effect of the Reaction Force Offset Control Corresponding to the Curvature

The reaction force offset control corresponding to the curvature determines a larger lateral force offset amount as the curvature of the white line increases, which is subtracted from the tire lateral force. The steering reaction force torque corresponding to the tire lateral force that is calculated by the SAT calculation unit **35**, that is, the steering reaction force characteristic representing the steering reaction force torque corresponding to the self-aligning torque is thereby offset in the same coding direction as the self-aligning torque, as the curvature of the white line increases, as illustrated in FIG. **12**. FIG. **12** illustrates a case of a right curve, and in the case of a left curve the offset is in the opposite direction of FIG. **12**.

Conventionally, in an SBW system in which the steering unit and the turning unit are mechanically detached, a steering reaction force characteristic that simulates a steering reaction force corresponding to the self-aligning torque in a conventional steering device is set, and the steering reaction force is applied to the steering wheel based on the steering reaction force characteristic; at this time, the relationship between the steering angle of the steering wheel and the turning torque of the driver has the characteristic A illustrated in FIG. **13**. That is, the absolute value of the turning torque increases as the absolute value of the steering angle increases, and the change amount of the steering torque with respect to the change amount of the steering angle increases when the absolute value of the steering angle is small, as compared to when large.

Here, a case is considered in which the driver changes the steering retention torque to adjust the course during turning. In FIG. **13**, when the driver reduces the steering retention torque to T_2 from a state in which the steering angle θ_1 is retained with a steering retention torque T_1, the steering angle becomes θ_2, and the turning angle of the front wheels **5**L, **5**R decreases due to the decrease in the steering angle. At this time, due to the steering reaction force characteristic in the SBW system described above, the steering angle varies greater with respect to the change in the steering retention torque as the curvature of the curve increases. In other words, the sensitivity of the vehicle with respect to the steering torque increases as the curvature of the curve increases; as a result, there is a problem that adjusting the course is difficult.

In contrast, in the reaction force offset control corresponding to the curvature of the first embodiment, by offsetting the steering reaction force characteristic, which represents the steering reaction force torque corresponding to the self-aligning torque, more in the same coding direction as the self-aligning torque as the curvature of the white line increases, the characteristic representing the relationship between the steering angle and the turning torque is offset in the same coding direction as the steering angle, as illustrated in FIG. **14**, and characteristic A changes to characteristic B. The change amount of the steering angle with respect to the change amount of the steering retention torque thereby decreases as the curvature of the white line increases; even when the driver reduces the steering retention torque to T_4 and the reduction amount of the steering retention torque $\Delta T_{3\text{-}4}$ is the same as the reduction amount of the prior art $\Delta T_{1\text{-}2}$ illustrated in FIG. **13**, the reduction amount of the steering angle $\Delta\theta_{14}$ will become smaller than the reduction amount of the prior art $\Delta\theta_{1\text{-}2}$. That is, a variation in the steering angle with respect to the change in the steering retention torque can be made smaller as the curvature of the curve increases, and the sensitivity of the vehicle with respect to the steering torque can be reduced; as a result, the behavior change of the vehicle becomes gradual, and facilitating the adjustment of the course by the driver is possible. Additionally, since the steering retention torque T_3 ($<T_1$) for maintaining the steering angle θ_1 can be made to be smaller than that of the prior art, the steering load of the driver while turning can be reduced.

Conventionally, technology that aims to reduce the steering load of the driver while turning, which reduces the slope of the steering reaction force characteristic more as the curvature of the white line increases, is known; however, in the conventional technology, variability in the steering angle with respect to the change in the steering retention torque increases as the curvature increases, so the sensitivity of the vehicle with respect to the steering torque increases. That is, realizing both a reduction in the steering load of the driver during turning and facilitating the adjustment of the course are possible by offsetting the steering reaction force characteristic in the same direction as the self-aligning torque in accordance with the curvature of the white line.

Steering Reaction Force Torque Offset Unit

FIG. **15** is a control block view of a steering reaction force torque offset unit **36**. A yaw angle calculation unit **36*a*** calculates the yaw angle at the forward gazing point. Easily and precisely detecting the yaw angle is possible by calculating the yaw angle based on an image of the traveling path captured by the camera **17**. A lateral position calculation unit **36*b*** calculates each of the lateral positions with respect to the left and right white lines at the forward gazing point and the lateral position with respect to the left and right white lines at the current position. Here, when the host vehicle moves to an adjacent traveling lane beyond the white line, that is, when a lane change occurs, the lateral position calculation unit **36*b*** replaces the lateral position with respect to the left and right white lines at the current position. That is, the lateral position with respect to the left white line before reaching the white line is set as the lateral position with respect to the right white line after reaching the white line, and the lateral position with respect to the right white line before reaching the white line is set as the lateral position with respect to the left white line after reaching the white line. When lane changing to a traveling lane with a different lane width, the lateral position is corrected by multiplying the value W_2/W_1, obtained by dividing the lane width W_2 of the traveling lane after the lane change by the lane width W_1 of the traveling lane before the lane change, to the replaced lateral position. Here, the lane width information of each traveling lane is acquired from a navigation system **24**. A deviation margin time based reaction force calculation unit **39** calculates a reaction force corresponding to the deviation margin time based on the vehicle speed, the lateral position with respect to the left and right white lines at the forward gazing point, and the turn signal from the turn signal switch **43**. The details of the deviation margin time based reaction force calculation unit **39** will be described below. A lateral position based reaction force calculation unit **40** calculates the reaction force corresponding to the lateral position, based on the lateral position with respect to the left and right white lines at the current position and the turn signal from the turn signal switch **43**. The details of the lateral position based reaction force calculation unit **40** will be described below. A reaction force selection unit **36*c*** selects that with the larger absolute value from among the reaction force corresponding to the deviation margin time and the reaction force corresponding to the lateral position as the steering reaction force torque offset amount.

A limiter processing unit **36*d*** limits the maximum value and the upper limit of the change rate of the steering reaction force torque offset amount. For example, the maximum value is 2 Nm and the upper limit of the change rate is 10 Nm/s. Additionally, the limiter processing unit **36*d*** limits the change rate of the steering reaction force torque offset amount in accordance with the turn signal from the turn signal switch **43**. Specifically, the absolute value of the increase gradient when the turn signal is switched from ON to OFF is made smaller than the absolute value of the decrease gradient when the turn signal is switched from OFF to ON. Here, the absolute value of the decrease gradient of the steering reaction force torque offset amount when the turn signal is switched from OFF to ON shall be a larger value than the absolute value of the decrease gradient of the disturbance suppression command turning angle when the turn signal is switched from OFF to ON in the limiter processing unit **32*i***.

FIG. **16** is a control block view of a deviation margin time based reaction force calculation unit **39**. A multiplier **39*a*** determines the lateral speed of the vehicle by multiplying the vehicle speed and the yaw angle. A divider **39*b*** determines the deviation margin time with respect to the left white line by dividing the lateral position with respect to the left white line at the forward gazing point by the lateral speed. A divider **39*c*** determines the deviation margin time with respect to the right white line by dividing the lateral position with respect to the right white line at the forward gazing point by the lateral speed. A deviation margin time selection unit **39*d*** selects the shorter of the deviation margin times with respect to the left and right white lines as the deviation margin time. A deviation margin time reaction force calculation unit **39*e*** corresponding to the deviation margin time calculates the reaction force corresponding to the deviation margin time, based on the deviation margin time. The reaction force corresponding to the deviation margin time is inversely proportional to the deviation margin time (proportional to the inverse of the deviation margin time) and has the characteristic of becoming almost zero at three seconds or more. The turn signal gain calculation unit **39*f*** outputs 1 when the turn signal is OFF and outputs a value smaller than 1 (for example 0.2) when the turn signal is ON. The multiplier **39*g*** multiplies each of the outputs from the reaction force calculation unit **39*e*** corresponding to the deviation margin time and the turn signal gain calculation unit **39*f*** to determine a reaction force corresponding to the final deviation margin time.

FIG. **17** is a control block view of a lateral position based reaction force calculation unit **40**. A subtracter **40*a*** determines the lateral position deviation with respect to the left lane by subtracting the lateral position with respect to the left lane from a target left lateral position that is set beforehand (for example, 90 cm). A subtracter **40***b* determines the lateral position deviation with respect to the right lane by subtracting the lateral position with respect to the right lane from a target right lateral position that is set beforehand (for example, 90 cm). A lateral position deviation selection unit **40***c* selects the larger of the lateral position deviations with respect to the left and right lanes as the lateral position deviation. A lateral position deviation based reaction force calculation unit **40***d* calculates the reaction force corresponding to the lateral position, based on the lateral position deviation. The reaction force corresponding to the lateral position shall have a characteristic of increasing as the lateral position deviation increases, and an upper limit is set thereon. The turn signal gain calculation unit **40***e* outputs 1 when the turn signal is OFF and outputs a value smaller than 1 (for example 0.2) when the turn signal is ON. A multiplier **40***f* multiplies each of the outputs from the lateral position deviation reaction force calculation unit **40***d* corresponding to the lateral position and the turn signal gain calculation unit **40***e* to determine a reaction force corresponding to the final lateral position.

Effect of the Reaction Force Offset Control Corresponding to the Lateral Position

The reaction force offset control corresponding to the lateral position adds the reaction force corresponding to the lateral position to the steering reaction force torque as the steering reaction force torque offset amount. The steering reaction force characteristic representing the steering reaction force torque corresponding to the self-aligning torque is thereby offset in a direction in which the absolute value of the steering reaction force torque increases as the distance to the white line decreases, as illustrated in FIG. **18**. FIG. **18** illustrates a case of being close to the right lane, and in the case of being close to the left lane the offset is in the opposite direction of FIG. **18**.

Here, a case is considered in which the traveling position of the vehicle shifts to the right side due to the driver suddenly steering to the right, after which the driver returns the traveling position to the vicinity of the center of the traveling lane with corrective steering, in a conventional steering reaction force control. The steering angle and the steering torque when the driver conducts a sudden operation shall be the position of point P_1 on the characteristic A in FIG. **19**. The characteristic A shall be a characteristic representing the relationship between the steering angle and the steering torque when setting a steering reaction force characteristic simulating a conventional steering device, in the same manner as FIG. **13**. Since turning the front wheel to the left is necessary in order to return the traveling position to the vicinity of the center of the traveling lane from this state, following a return steering to the steering angle neutral position, the driver increases the steering from the steering angle neutral position and matches the steering wheel to a target angle θ_5. At this time, in the conventional technology described above, the steering angle neutral position (the steering angle zero point) and the steering torque neutral position (the steering torque zero point) match, and decreasing the steering torque until the steering angle neutral position while increasing the steering torque after exceeding the steering angle neutral position is necessary. In other words, when conducting corrective steering straddling the steering angle neutral position, the sign of the steering torque is inverted, and the direction in which the driver controls the force is switched; since the change amount of the steering angle with respect to the change amount of the steering torque is significantly smaller in the vicinity of the steering torque neutral position, as compared to other steering angle regions, the steering load on the driver is large, and controlling the steering wheel to be at the target angle θ_5 is difficult. Thus, there is the problem that the traveling position of the vehicle is more readily overshot, leading to an increase in the corrective steering amount.

In contrast, in the reaction force offset control corresponding to the lateral position of the first embodiment, by offsetting the steering reaction force torque corresponding to the self-aligning torque more in a direction in which the absolute value of the steering reaction force torque increases as the distance to the white line decreases, the characteristic representing the relationship between the steering angle and the steering torque is offset in the direction in which the absolute value of the steering torque increases, as illustrated in FIG. **20**, and characteristic A changes continuously to characteristic C, as the distance to the white line decreases. At this time, increasing the steering torque in order to maintain the steering angle is necessary; therefore, if the steering torque is constant, the steering wheel **6** gradually returns to the steering angle neutral position (point P_1->point P_2), thereby suppressing the traveling position of the vehicle from shifting to the right side due to the driver suddenly steering. On the other hand, when the driver maintains the steering angle, the steering angle and the steering torque move from point P_1 to point P_3. When the driver conducts corrective steering from this state, since the steering torque neutral position is offset more to the steering increase side than the steering angle neutral position in characteristic C, the sign of the steering torque is not inverted before reaching the steering torque neutral position during the increased steering operation from the steering angle neutral position. Thus, the driver is able to control the turning angle of the front wheels **5**L, **5**R by only reducing the steering torque and stopping the rotation of the steering wheel **6** when the steering wheel **6** is turned to the target angle. That is, the reaction force offset control corresponding to the lateral position of the first embodiment is able to facilitate the corrective steering of the driver since the direction in which the driver controls the force is not readily switched. As a result, the traveling position of the vehicle is not readily overshot, and the corrective steering amount can be reduced.

Conventionally, a technology is known in which the object is to suppress the traveling position from shifting due to a sudden operation by the driver, by increasing the steering reaction force when approaching the white line; however, in the conventional technology, the steering wheel is simply made heavier when approaching the white line, and the steering torque neutral position in the steering reaction force characteristic always matches with the steering angle neutral position; therefore, the sign of the steering torque is inverted in the corrective steering that straddles the steering angle neutral position, and the steering load of the driver is not reduced. In other words, by offsetting the steering reaction force torque corresponding to the self-aligning torque more in a direction in which the absolute value of the steering reaction force torque increases as the distance to the white line decreases, realizing both the suppression of the shifting of the traveling position and a reduction in the steering load of the driver is possible.

Additionally, in the reaction force offset control corresponding to the lateral position of the first embodiment, the offset amount is configured to be greater as the distance to the white line decreases; as a result, the steering torque neutral position is offset to a position that is further separated from the steering angle neutral position as the distance to the white line decreases. When the driver conducts corrective steering to return the traveling position of the vehicle to the vicinity of the center of the traveling lane, increasing the steering increase operation amount from the steering angle neutral position as the white line comes closer is necessary. At this time, when the offset amount of the steering torque neutral position with respect to the steering angle neutral position is small, there is the possibility that the steering torque surpasses the neutral position and the sign of the steering torque is inverted before the steering wheel is turned to the target angle. Thus, suppressing the steering torque from surpassing the neutral position is possible by increasing the offset amount as the distance to the white line decreases.

In the reaction force offset control corresponding to the lateral position of the first embodiment, the lateral position calculation unit **36***b* switches the lateral position with respect to the left and right white lines at the current position when the host vehicle reaches the white line. The reaction force offset control corresponding to the lateral position is configured so that the host vehicle readily returns to the vicinity of the center of the traveling lane by increasing the steering reaction force as the host vehicle gets farther away from the vicinity of the center of the traveling lane. In other words, the yaw angle integrated value (the lateral position change) is considered to be a disturbance, and the steering reaction force is controlled so that the vehicle is guided in a direction in which the yaw angle integrated value is eliminated. Consequently, resetting the yaw angle integrated value when a lane change has been conducted is necessary. This is because, if the yaw angle integrated value is not reset, the steering reaction force for returning the vehicle to the vicinity of the center of the traveling lane before the lane change will continue to act even after the lane change, and the operation of the driver will be inhibited. If the integrated value is simply set to be zero, guiding the vehicle to the vicinity of the center of the traveling lane after the lane change will not be possible.

Therefore, in the first embodiment, since a deliberate operation of the driver can be considered when the host vehicle reaches the white line, in that case, by switching the lateral position with respect to the left and right white lines at the current position, in other words, by inverting the sign of the yaw angle integrated value, the position to which the host vehicle is guided is switched from the vicinity of the center of the traveling lane before the lane change to the vicinity of the center of the traveling lane after the lane change; therefore, a steering reaction force for guiding the host vehicle to the vicinity of the center of the traveling lane after the lane change can be generated. At this time, in order to consider the ratio W_2/W_1 of the lane width W_2 of the traveling lane after the lane change with respect to the lane width W_1 of the traveling lane before the lane change, setting an accurate lateral position is possible, and setting an optimum offset amount for guiding the host vehicle to the vicinity of the center of the traveling lane is possible.

Effect of the Reaction Force Offset Control Corresponding to the Deviation Margin Time

The reaction force offset control corresponding to the deviation margin time adds the reaction force corresponding to the deviation margin time to the steering reaction force torque as the steering reaction force torque offset amount. The steering reaction force characteristic representing the steering reaction force torque corresponding to the self-aligning torque is thereby offset in a direction in which the absolute value of the steering reaction force torque increases as deviation margin time decreases, as illustrated in FIG. **18**. FIG. **18** illustrates a case of being close to the right lane, and in the case of being close to the left lane the offset is in the opposite direction of FIG. **18**.

Accordingly, the characteristic representing the relationship between the steering angle and the steering torque is offset in a direction in which the absolute value of the steering torque increases, and characteristic A changes continuously to characteristic C, as the deviation margin time decreases, as illustrated in FIG. **20**. At this time, increasing the steering torque in order to maintain the steering angle is necessary; therefore, if the steering torque is constant, the steering wheel **6** gradually returns to the steering angle neutral position (point P_1->point P_2), thereby suppressing the traveling position of the vehicle from shifting to the right side due to the driver suddenly steering. On the other hand, when the driver maintains the steering angle, the steering angle and the steering torque move from point P_1 to point P_3. When the driver conducts corrective steering from this state, since the steering torque neutral position is offset more to the steering increase side than the steering angle neutral position in characteristic C, the sign of the steering torque is not inverted before reaching the steering torque neutral position during the steering increase operation from the steering angle neutral position. Thus, the driver is able to control the turning angle of the front wheels **5**L, **5**R by only reducing the steering torque and stopping the rotation of the steering wheel **6** when the steering wheel **6** is turned to the target angle. That is, the reaction force offset control corresponding to the deviation margin time of the first embodiment is able to facilitate the corrective steering of the driver since the direction in which the driver controls the force is not readily switched. As a result, the traveling position of the vehicle is not readily overshot, and the corrective steering amount can be reduced.

Additionally, in the reaction force offset control corresponding to the deviation margin time of the first embodiment, the offset amount is configured to increase as the deviation margin time decreases; as a result, the steering torque neutral position is offset to a position that is further separated from the steering angle neutral position as the deviation margin time decreases. When the driver conducts corrective steering for returning the traveling position of the vehicle to the vicinity of the center of the traveling lane, the vehicle is more likely to be closer to the white line as the deviation margin time decreases, and increasing the amount of steering from the steering angle neutral position as the white line becomes closer is necessary. At this time, when the offset amount of the steering torque neutral position with respect to the steering angle neutral position is small, there is the possibility that the steering torque surpasses the neutral position and the sign of the steering torque is inverted before the steering wheel is turned to the target angle. Thus, suppressing the steering torque from surpassing the neutral position is possible by increasing the offset amount as the distance to the white line decreases.

Effect of the Reaction Force Offset Control Corresponding to the Lateral Position and the Deviation Margin Time

In the steering reaction force control unit **20**, that with the larger absolute value from among the reaction force corresponding to the deviation margin time and the reaction force corresponding to the lateral position is selected as the steering reaction force torque offset amount in the steering torque offset unit **36**, and the steering reaction force torque offset amount is added to the steering reaction force torque in the adder **20***c*. The steering reaction force characteristic is thereby offset in a direction in which the absolute value of the steering reaction force torque increases in accordance with the deviation margin time or the lateral position. In the reaction force offset control corresponding to the deviation margin time, the reaction force corresponding to the deviation margin time is zero when the host vehicle and the white line are parallel, that is, when the yaw angle is zero. Consequently, even if the host vehicle is in a position close to the white line, when the yaw angle is small, only a small reaction force can be output. In contrast, in the reaction force offset control corresponding to the lateral position, a reaction force (a reaction force corresponding to the lateral position) is generated to be proportionate to the distance to the white line; therefore, a larger reaction force can be output as the distance to the white line decreases, and readily returning the host vehicle to the vicinity of the center of the traveling lane is possible.

On the other hand, in the reaction force offset control corresponding to the lateral position, when the host vehicle is in the vicinity of the center of the traveling lane, the reaction force corresponding to the lateral position is zero. Consequently, even in the vicinity of the center of the traveling lane, when the yaw angle is large and the vehicle speed is high, the white line is reached in a short period of time while increasing the steering reaction force with good responsiveness is difficult. In contrast, in the reaction force offset control corresponding to the deviation margin time, since a reaction force (a reaction force corresponding to the deviation margin time) is generated in accordance with the deviation margin time, and the reaction force has the characteristic of rapidly increasing when the deviation margin time becomes equal to or less than 3 seconds, suppressing lane deviation by increasing the steering reaction force with good responsiveness is possible even when reaching the white line in a short period of time. Thus, by combining the reaction force offset control corresponding to the deviation margin time and the reaction force offset control corresponding to the lateral position, effectively suppressing lane deviation while applying a stable reaction force in accordance with the distance to the white line is possible. At this time, by using that with the larger absolute value from among the reaction force corresponding to the deviation margin time and the reaction force corresponding to the lateral position, always applying the optimum required steering reaction force is possible.

Control Amount Suppression Effect During Lane Change

The turn signal gain calculation units **39***f*, **40***e* decrease the turn signal gain when the turn signal becomes ON. The steering reaction force will thereby not be increased rapidly even when approaching the white line when conducting a lane change, by limiting the steering reaction force torque offset amount, which is the steering reaction force control amount of the reaction force offset control corresponding to the deviation margin time and the lateral position; as a result, the driver is able to conduct a lane change smoothly. If each control described above were to be configured to stop during a lane change, time would be required until the controls start to be effective again after the lane change, generating a delay in the control; in contrast, in the first embodiment, only the gain (turn signal gain) for determining the steering reaction force control amount is reduced, and the controls are continued; as a result, an appropriate steering reaction force control amount can be obtained from immediately after the lane change. Also, by greatly reducing the gain (1->0.2) when the driver turns the turn signal switch ON, the driver can be made to notice that the steering reaction force control amount has been suppressed at the lane change start time from the reduction in the steering reaction force, obtaining a feeling of moderation. The same applies to the turn signal gain calculation unit **38***g*; since the lateral position F/B control is continued, an appropriate turn control amount can be obtained from immediately after the lane change, and the driver can be made to notice that the turn control amount has been suppressed at the lane change start time from the reduction in the disturbance suppression command turning angle, obtaining a feeling of moderation.

The limiter processing unit **36***d* makes the absolute value of the increase gradient of the steering reaction force torque offset amount when the turn signal is switched from ON to OFF smaller than the absolute value of the decrease gradient of the steering reaction force torque offset amount when the turn signal is switched from OFF to ON. In other words, the steering reaction force torque offset amount is reduced to a value of turn signal gain=0.2 at an early stage when a lane change is started, and the steering reaction force torque offset amount is gradually restored to a value of turn signal gain=1 after the lane change. As described above, in order to reduce the steering reaction force at the lane change start time to a level that a driver can notice, reducing the steering reaction force control amount at an early stage is necessary. On the other hand, if the steering reaction force control amount is increased at an early stage when restoring the steering reaction force control amount after a lane change, the steering reaction force increases rapidly, imparting discomfort to the driver. Therefore, by making the absolute value of the increase gradient smaller than the absolute value of the decrease gradient of the steering reaction force control amount, a rapid increase in the steering reaction force can be suppressed, and discomfort imparted to the driver can be reduced. The same applies to the limiter processing unit **32***i*; a rapid change in the turning angle can be suppressed, and discomfort imparted to the driver can be reduced.

The limiter processing unit **32***i* makes the absolute value of the decrease gradient of the disturbance suppression command turning angle when the turn signal is switched from OFF to ON a smaller value than the absolute value of the decrease gradient of the steering reaction force torque offset amount when the turn signal is switched from OFF to ON. This is because, while a rapid change in the steering reaction force has little effect on the vehicle behavior, a rapid change in the disturbance suppression command turning angle will have an effect on the vehicle behavior. Also, reducing the steering reaction force torque offset amount is more readily conveyed to the driver directly and thus is preferable as a means to impart a feeling of moderation, compared to reducing the disturbance suppression command turning angle. Thus, fluctuation in the vehicle behavior at the lane change start time can be suppressed by making the absolute value of the decrease gradient of the disturbance suppression command turning angle smaller than the absolute value of the decrease gradient of the steering reaction force torque offset amount.

The effects listed below can be obtained with the first embodiment, as described above.

(1) Comprises a steering reaction force control unit **20** that sets a steering reaction force characteristic to coordinates, of which the coordinate axes are self-aligning torque and steering reaction force, so that the self-aligning torque increases as the steering reaction force increases, and applies a steering reaction force corresponding to the self-aligning torque to a steering unit **1** based on the steering reaction force characteristic; a steering reaction force torque offset unit **36** that offsets the steering reaction force characteristic at the coordinates more in a direction in which the absolute value of the steering reaction force increases as the lateral position of a host vehicle becomes closer to a white line; a turn signal switch **43** for detecting a turn signal operation; and a limiter processing unit **36***d* that suppresses the offset of the steering reaction force characteristic when a turn signal operation is started and releases the suppression of the offset of the steering reaction force characteristic when the turn signal operation is ended, wherein the limiter processing unit **36***d* makes the absolute value of the increase gradient when releasing the suppression

of the offset smaller than the absolute value of the decrease gradient when suppressing the offset. Since the offset of the steering reaction force characteristic is gradually restored when the turn signal operation is ended, a rapid increase in the steering reaction force can thereby be suppressed, and the discomfort imparted to the driver can be reduced. Also, since the steering torque neutral position is offset more to the steering increase side than the steering angle neutral position, the sign of the steering torque being inverted during corrective steering is suppressed. As a result, since the direction in which the driver controls the force is not readily switched, the steering load of the driver can be reduced. Also, a stable reaction force can be applied in accordance with the distance to the white line.

(2) Comprises a steering reaction force control unit **20** that sets a steering reaction force characteristic to coordinates, of which the coordinate axes are self-aligning torque and steering reaction force, so that the self-aligning torque increases as the steering reaction force increases, and applies a steering reaction force corresponding to the self-aligning torque to a steering unit **1** based on the steering reaction force characteristic; a steering reaction force torque offset unit **36** that offsets the steering reaction force characteristic at the coordinates more in a direction in which the absolute value of the steering reaction force increases as the lateral position of a host vehicle becomes closer to a white line; a turn signal switch **43** for detecting a turn signal operation; and a limiter processing unit **36*d*** that suppresses the offset of the steering reaction force characteristic when a turn signal operation is started and releases the suppression of the offset of the steering reaction force characteristic when the turn signal operation is ended, wherein the limiter processing unit **36*d*** makes the absolute value of the increase gradient when releasing the suppression of the offset smaller than the absolute value of the decrease gradient when suppressing the offset. Since the offset of the steering reaction force characteristic is gradually restored when the turn signal operation is ended, a rapid increase in the steering reaction force can thereby be suppressed, and the discomfort imparted to the driver can be reduced. Also, since the steering torque neutral position is offset more to the steering increase side than the steering angle neutral position, the sign of the steering torque being inverted during corrective steering is suppressed. As a result, since the direction in which the driver controls the force is not readily switched, the steering load of the driver can be reduced. Also, lane deviation can be effectively suppressed.

(3) Comprises a turning motor **13** (turning actuator) for varying the turning amount of the turning unit **2**; a repulsive force calculation unit **38** (turn control means) corresponding to the lateral position that applies a turn control amount, in which the turning amount in a direction farther away from the white line is increased as the lateral position of the host vehicle becomes closer to the white line, to the turning motor **13**; and a limiter processing unit **32*i*** (control amount suppression means) that suppresses the turn control amount when a turn signal operation is started and releases the suppression of the turn control amount when the turn signal operation is ended, wherein the limiter processing unit **32*i*** makes the absolute value of the increase gradient when releasing the suppression of the turn control amount smaller than the absolute value of the decrease gradient when suppressing the turn control amount. Since the turn control amount is gradually restored when the turn signal operation is ended, a rapid change in the turning angle can thereby be suppressed, and the discomfort imparted to the driver can be reduced.

(4) The limiter processing unit **32*i*** makes the absolute value of the decrease gradient when suppressing the turn control amount smaller than the absolute value of the decrease gradient when suppressing the offset of the steering reaction force characteristic. Fluctuation in the vehicle behavior at the lane change start time can thereby be suppressed.

(5) A steering reaction force characteristic is set to coordinates, of which the coordinate axes are self-aligning torque and steering reaction force, so that the self-aligning torque increases as the steering reaction force increases, and upon applying a steering reaction force corresponding to the self-aligning torque to a steering unit **1** based on the steering reaction force characteristic to offset the steering reaction force characteristic at the coordinates more in a direction in which the absolute value of the steering reaction force increases as the lateral position of a host vehicle becomes closer to a white line, the offset of the steering reaction force characteristic is suppressed when a turn signal operation is started while the suppression of the offset of the steering reaction force characteristic is released when the turn signal operation is ended so that the absolute value of the increase gradient when releasing the suppression of the offset becomes smaller than the absolute value of the decrease gradient when suppressing the offset. Since the offset of the steering reaction force characteristic is gradually restored when the turn signal operation is ended, a rapid increase in the steering reaction force can thereby be suppressed, and the discomfort imparted to the driver can be reduced.

(6) Comprises a turn signal switch **43** for detecting a turn signal operation; and a steering reaction force control unit **20** that sets a steering reaction force characteristic to coordinates, of which the coordinate axes are self-aligning torque and steering reaction force, so that the self-aligning torque increases as the steering reaction force increases, and upon applying a steering reaction force corresponding to the self-aligning torque to a steering unit **1** based on the steering reaction force characteristic to offset the steering reaction force characteristic at the coordinates more in a direction in which the absolute value of the steering reaction force increases as the lateral position of a host vehicle becomes closer to a white line, the offset of the steering reaction force characteristic is suppressed when a turn signal operation is started while the suppression of the offset of the steering reaction force characteristic is released when the turn signal operation is ended so that the absolute value of the increase gradient when releasing the suppression of the offset becomes smaller than the absolute value of the decrease gradient when suppressing the offset. Since the offset of the steering reaction force characteristic is gradually restored when the turn signal operation is ended, a rapid increase in the steering reaction force can thereby be suppressed, and the discomfort imparted to the driver can be reduced.

(7) A steering reaction force characteristic is set to coordinates, of which the coordinate axes are self-aligning torque and steering reaction force, so that the self-aligning torque increases as the steering reaction force increases, and upon applying a steering reaction force corresponding to the self-aligning torque to a steering unit **1** based on the steering reaction force characteristic to offset the steering reaction force characteristic at the coordinates more in a direction in which the absolute value of the steering reaction force increases as the margin time, which is the time required for a host vehicle to reach a white line, becomes shorter, the offset of the steering reaction force characteristic is suppressed when a turn signal operation is started while the suppression of the offset of the steering reaction force characteristic is released when the turn signal operation is ended so that the absolute value of the increase gradient when releasing the

suppression of the offset becomes smaller than the absolute value of the decrease gradient when suppressing the offset. Since the offset of the steering reaction force characteristic is gradually restored when the turn signal operation is ended, a rapid increase in the steering reaction force can thereby be suppressed, and the discomfort imparted to the driver can be reduced.

(20) Comprises a turn signal switch **43** for detecting a turn signal operation; and a steering reaction force control unit **20** that sets a steering reaction force characteristic to coordinates, of which the coordinate axes are self-aligning torque and steering reaction force, so that the self-aligning torque increases as the steering reaction force increases, and upon applying a steering reaction force corresponding to the self-aligning torque to a steering unit **1** based on the steering reaction force characteristic to offset the steering reaction force characteristic at the coordinates more in a direction in which the absolute value of the steering reaction force increases as the margin time, which is the time required for a host vehicle to reach a white line, becomes shorter, the offset of the steering reaction force characteristic is suppressed when a turn signal operation is started while the suppression of the offset of the steering reaction force characteristic is released when the turn signal operation is ended so that the absolute value of the increase gradient when releasing the suppression of the offset becomes smaller than the absolute value of the decrease gradient when suppressing the offset. Since the offset of the steering reaction force characteristic is gradually restored when the turn signal operation is ended, a rapid increase in the steering reaction force can thereby be suppressed, and the discomfort imparted to the driver can be reduced.

Second Embodiment

FIG. **21** is a system view illustrating a steering system of a vehicle of the second embodiment. The locations common with the first embodiment are given the same name and codes, and their explanations are omitted. The steering device of the second embodiment is mainly configured by a steering unit **1**, a turning unit **2**, and an EPS controller **25**, and the steering unit **1** that receives a steering input of a driver and the turning unit **2** that turns a left and a right front wheel (turning wheels) **5**FL, **5**FR are mechanically coupled. The steering unit **1** comprises a steering wheel **6**, a column shaft **7**, and a torque sensor **26**. The torque sensor **26** detects a steering torque of the driver that is inputted from the steering wheel **6** to the column shaft **7**. The turning unit **2** comprises a pinion shaft **11**, a steering gear **12**, and a power steering motor **27**. The pinion shaft **11** is connected to the column shaft **7** via a torsion bar of the torque sensor **26**. The power steering motor **27** is, for example, a brushless motor, in which the output shaft is connected to a rack gear **15** via an unillustrated decelerator, and outputs an assist torque for assisting the steering force of the driver to a rack **16**, in response to a command from the EPS controller **25**.

The vehicle speed (vehicle body speed) detected by an image of the traveling path in front of the host vehicle captured by a camera **17** and a vehicle speed sensor **18**, in addition to the above-described torque sensor **26**, are inputted to the EPS controller **25**. The EPS controller **25** comprises an assist torque control unit **28**, and an image processing unit **21**. The assist torque control unit **28** generates a command assist torque based on each piece of input information, and outputs the generated command assist torque to a current driver **29**. The current driver **29** controls a command current to the power steering motor **27** with a torque feedback that matches an actual assist torque that is inferred from a current value of the power steering motor **27** with the command assist torque. The image processing unit **21** recognizes a traveling lane left and right white lines (the traveling path dividing lines) by image processing, such as by edge extraction from an image of a traveling path in front of a host vehicle captured by the camera **17**.

Assist Torque Control Unit

FIG. **22** is a control block view of the assist torque control unit **28**. The assist torque calculation unit **41** calculates an assist torque with reference to an assist torque map that is set beforehand, based on the steering torque and the vehicle speed. The assist torque characteristic in the assist torque map has a characteristic of becoming larger as the absolute value of the steering torque increases, or the vehicle speed decreases. The assist torque offset unit **42** calculates an assist torque offset amount for offsetting the assist torque characteristic in an assist torque offset control corresponding to the lateral position or the deviation margin time, based on vehicle speed and an image of a traveling path in front of the host vehicle. The details of the assist torque offset unit **42** will be described below. A subtracter **28*a*** outputs a value obtained by subtracting the assist torque offset amount from the assist torque to the current driver **29** as the final command assist torque.

Assist Torque Offset Unit

FIG. **23** is a control block view of an assist torque offset unit **42**. A reaction force selection unit **42*c*** selects that with the larger absolute value among the reaction force corresponding to the deviation margin time and the reaction force corresponding to the lateral position as the assist torque offset amount.

Effect of the Assist Torque Offset Control Corresponding to the Lateral Position

The assist torque offset control corresponding to the lateral position subtracts the reaction force corresponding to the lateral position from the assist torque as the assist torque offset amount. The assist torque characteristic, representing the assist torque corresponding to the steering torque, is thereby offset in a direction in which the absolute value of the assist torque becomes smaller as the distance to the white line decreases, as illustrated in FIG. **24**. FIG. **24** illustrates a case of being close to the right lane, and in the case of being close to the left lane the offset is in the opposite direction of FIG. **18**. The characteristic representing the relationship between the steering angle and the steering torque thereby becomes the characteristic illustrated in FIG. **20** of the first embodiment; as a result, the same effect as the reaction force offset control corresponding to the lateral position of the first embodiment can be obtained.

Effect of the Assist Torque Offset Control Corresponding to the Deviation Margin Time

The assist torque offset control corresponding to the deviation margin time subtracts the reaction force corresponding to the deviation margin time from the assist torque as the assist torque offset amount. The assist torque characteristic, representing the assist torque corresponding to the steering torque, is thereby offset in a direction in which the absolute value of the assist torque becomes smaller as the deviation margin time decreases, as illustrated in FIG. **24**. FIG. **24** illustrates a case of being close to the right lane, and in the case of being close to the left lane the offset is in the opposite direction of FIG. **18**. The characteristic representing the relationship between the steering angle and the steering torque thereby becomes the characteristic illustrated in FIG. **20** of the first embodiment; as a result, the same effect as the reaction force offset control corresponding to the deviation margin time of the first embodiment can be obtained. The effect of the assist torque offset control corresponding to the lateral position and the deviation margin time in the second embodiment is the same as the effect of the reaction force offset control corresponding to the lateral position and the deviation margin time in the first embodiment. As described above, the second embodiment exerts the same effects as the first embodiment.

The invention claimed is:

1. A steering control device comprising:
   a steering reaction force control unit that
      sets a steering reaction force characteristic to coordinates, of which coordinates axes are self-aligning torque and steering reaction force,
         so that the self-aligning torque increases as the steering reaction force increases, and
      applies a steering reaction force to a steering unit based on the steering reaction force characteristic;
   an offset unit that offsets the steering reaction force characteristic at the coordinates more in a direction in which an absolute value of the steering reaction force is increased as a lateral position of a host vehicle becomes closer to a white line;
   a turn signal operation detection device that detects a turn signal operation; and
   an offset suppression unit that
      suppresses an offset of the steering reaction force characteristic when the turn signal operation started, and
      releases suppression of the offset of the steering reaction for characteristic when the turn signal operation is ended;
   the offset suppression unit makes an absolute value of an increase gradient when releasing the suppression of the offset smaller than an absolute value of a decrease gradient when suppressing the offset.

2. The steering control device according to claim 1, further comprising:
   a turning actuator configured to vary a turning amount of a turning unit;
   a turn control unit that applies a turn control amount to the turning actuator, in which the turning amount is a direction farther away from the white line is increased as the lateral position of the host vehicle becomes closer to the white line;
   a turn signal operation detection unit that detects a turn signal operation; and
   a turn control amount suppression unit that
      suppresses the turn control amount when the turn signal operation is started, and
      releases suppression of the turn control amount when the turn signal operation is ended;
   the turn control amount suppression unit makes an absolute value of an increase gradient when releasing suppression of the turn control amount smaller than an absolute value of a decrease gradient when suppressing the turn control amount.

3. The steering control device according to claim 2, wherein
   the turn control amount suppression unit makes the absolute value of the decrease gradient of the turn control amount when suppressing the turn control amount smaller than the absolute value of the decrease gradient of the turn control amount when suppressing the offset of the steering reaction force characteristic.

4. A steering control device comprising:
   a steering reaction force control unit that
      sets a steering reaction force characteristic to coordinates, of which coordinates axes are self-aligning torque and steering reaction force,
         so that the self-aligning torque increases as the steering reaction force increases, and
      applies a steering reaction force to a steering unit based on the steering reaction force characteristic;
   an offset unit that offsets the steering reaction force characteristic at the coordinates more in a direction in which an absolute value of the steering reaction force increases as a margin time, which is a time required for a host vehicle to reach a white line, becomes shorter; and
   an offset suppression unit that
      suppresses an offset of the steering reaction force characteristic when a turn signal operation is started, and
      releases the suppression of the offset of the steering reaction force characteristic when the turn signal operation is ended;
   the offset suppression unit makes an absolute value of an increase gradient when releasing suppression of the offset of the steering reaction force characteristic smaller than an absolute value of a decrease gradient when suppressing the offset of the steering reaction force characteristic.

5. The steering control device according to claim 4, further comprising:
   a turning actuator configured to vary a turning amount of a turning unit;
   a turn control unit that applies a turn control amount to the turning actuator, in which the turning amount in a direction farther away from the white line is increased as the lateral position of the host vehicle becomes closer to the white line;
   a turn signal operation detection unit that detects a turn signal operation; and
   a turn control amount suppression unit that
      suppresses the turn control amount when the turn signal operation is started, and
      releases suppression of the turn control amount when the turn signal operation is ended;
   the turn control amount suppression unit makes an absolute value of an increase gradient when releasing suppression of the turn control amount smaller than an absolute value of a decrease gradient when suppressing the turn control amount.

6. The steering control device according to claim 5, wherein
   the turn control amount suppression unit makes the absolute value of the decrease gradient of the turn control amount when suppressing the turn control amount smaller than the absolute value of the decrease gradient of the turn control amount when suppressing the offset of the steering reaction force characteristic.

7. steering control device comprising:
   a sensor for detecting a turn signal operation; and
   a controller that
      sets a steering reaction force characteristic to coordinates, of which coordinate axes are self-aligning torque and steering reaction force,
         so that the self-aligning torque increases as the steering reaction force increases, and
      upon applying a steering reaction force corresponding to the self-aligning torque to a steering unit based on the steering reaction force characteristic to offset the steering reaction force characteristic as the coordinates more in a direction in which an absolute value of the steering reaction force increases as a lateral position of a host vehicle becomes closer to a white line,

suppresses the offset of the steering reaction force characteristic when a turn signal operation is started and

releases suppression of the offset of the steering reaction force characteristic when the turn signal operation is ended

so that an absolute value of an increase gradient when releasing the suppression of the offset becomes smaller than an absolute value of a decrease gradient when suppressing the offset.

8. A steering control device comprising:

a sensor for detecting a turn signal operation; and

a controller that

sets a steering reaction force characteristic to coordinates, of which coordinate axes are self-aligning torque and steering reaction force, so that the self-aligning torque increases as the steering reaction force increases, and

upon applying a steering reaction force corresponding to the self-aligning torque to a steering unit based on the steering reaction force characteristic to offset the steering reaction force characteristic at the coordinates more in a direction in which an absolute value of the steering reaction force increases as a margin time, which is a time required for a host vehicle to reach a white line, becomes shorter,

suppresses the offset of the steering reaction force characteristic when a turn signal operation is started and

releases suppression of the offset of the steering reaction force characteristic when the turn signal operation is ended

so that an absolute value of an increase gradient when releasing the suppression of the offset becomes smaller than an absolute value of a decrease gradient when suppressing the offset.

* * * * *